Forests and Climate Change Working Paper 10

Forest Management and Climate Change: a literature review

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Forests and Climate Change Working Paper 10

Forest Management and Climate Change: a literature review

Food and Agriculture Organization of the United Nations
Rome, 2012

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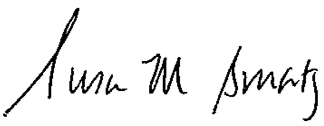
Foreword

This document is part of the publications series produced by the Forest and Climate Change Programme of FAO. The programme seeks to provide timely information and tools to a wide range of stakeholders, with the ultimate objective of assisting countries' efforts to mitigate and adapt to climate change through actions consistent with sustainable forest management.

FAO is currently developing guidelines to assist forest managers to understand, assess and implement climate change mitigation and adaptation measures. The guidelines will be applicable globally and will be relevant to all types of forests (boreal, temperate, and tropical), to all management objectives (production, conservation, protection and multi-purpose) and to all types of managers (public, private and community).

This document was written to facilitate the preparation of the guidelines. The objective was to determine if and how forest management is changing or could change in order to respond effectively to climate change challenges and mitigation opportunities. It reviews the current understanding of climate change impacts on forests and forest management, assesses the challenges that these bring to forest managers at the forest management unit level and provides examples of how forest managers have responded to these challenges. The document also identifies what is needed to create an enabling policy, legal and institutional environment that would support forest managers' efforts in mitigation and adaptation. The document provides us with a useful basis of information for the development of the guidelines, but we also hope that it will be valuable to others in their efforts to make climate change adaptation and mitigation a reality on the ground.



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Acknowledgments

This publication is the result of one of the outcomes under the umbrella of the Climate Change Guidelines for Forest Managers (*in progress*). FAO wishes to express its gratitude to the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) for the preparation of this document. Mr. Bas Louman coordinated the preparation and comments were provided by Susan Braatz, Diego Delgado, Francis Putz, Simmone Rose, Maria Ruiz-Villar, Jesper Tranberg and Mariel Yglesias. The report was edited and prepared for publication by Simmone Rose.

The publication has been developed with financial support from the FAO-Finland Forestry Programme "Sustainable forest management in a changing climate".

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Executive summary

This document summarizes knowledge and experiences in forest management as a response to climate change, based on a literature review and a survey of forest managers. This is part of an FAO-led process to prepare climate change guidelines for forest managers. It examines climate change impacts on forests and forest managers throughout the world. The document also reviews the main perceived challenges that climate change poses to forests and their managers. It summarizes experiences in preparing for and reacting to climate change in different types of forests. Finally, it indicates a number of gaps in enabling conditions (related to knowledge, institutional setting and culture) that hamper forest managers from responding effectively to climate change and its impacts.

The document concludes that a number of forest managers worldwide already have in place interesting strategies for climate change. Unfortunately, in few cases are proper monitoring systems in place that allow society and forest managers to assess the effectiveness and efficiency of the measures taken or of their social and environmental impacts. Often such measures and management strategies are designed in response to a perceived risk of negative climate change impacts rather than in response to incentive schemes, such as payment for environmental services or market driven schemes such as certification. The document provides a number of recommendations for forest managers to better prepare for climate change opportunities and challenges to come.

Climate change impacts

In general, climate change will affect the forest conditions (area, health and vitality and biodiversity), allowing increases in growth rates in some areas while endangering the survival of species and forest communities in others. Temperature, availability of water and changes in seasonality may all become limiting factors, depending on geographic area, original climatic conditions, species diversity and human activities. Most commonly, these changes will affect the frequency and intensity of fires and insect pests and diseases, as well as damage done by extreme weather conditions, such as droughts, torrential rains and hurricane winds. In some cases, this may lead to expansion of forest areas; for example, temperate forests are expected to spread poleward. In other cases it may lead to reduction of forest areas, such as in the northeast Amazonian region, where forest dieback is expected to reach enormous proportions due to reduced availability of water, in combination with unsustainable land use practices. Provision of forest ecosystem services and goods will be altered by these changes, posing a number of new challenges to forest managers. In some areas, responses to climate change will affect the demand for forest products; for example, increased demand for forest-based fuels as a substitute for fossil fuels. Societies react to their perceptions of the actual and potential impacts of climate change on ecosystems by developing policies and legislation, as well as to changing requirements related to forest production and trade.

Forest managers' responses

A global survey by FAO found that, although most forest managers are aware of and concerned about climate change and its potential impacts, only few have clear ideas on how to prepare for and react to it. From these few, however, many interesting and important lessons may be learned. Possibly the biggest lesson is that sustainable forest management (SFM), the overarching vision for forests and associated principles that have been adopted by all members of the United Nations, is a sound foundation to guide forest managers' responses to climate change. SFM can help forest managers reduce the risk of damage and possible losses from changing climatic conditions and also to undertake effective mitigation actions.

Monitoring of changes is possibly the activity that would add most burden to forest management activities, since to date few effective and cheap ways to monitor changes have been found and implemented. It is nevertheless important for future forest management operations, as it is mainly through monitoring that forest managers will be alerted to changes early on. In addition, several of the opportunities that are currently being discussed in relation to climate change, such as payment for ecosystem services, require monitoring to identify and measure services rendered.

A range of management activities will contribute to maintaining or increasing the adaptive capacity of forests. The include, among others, actions oriented to maintaining forest health and vitality (e.g. by application of appropriate silvicultural treatments and by fire, pest and disease management) and to conserving or enhancing biodiversity in forests (e.g. by effective management of forest conservation areas, enhancing connectivity between forest areas). Many of these management actions also contribute to climate change mitigation through reducing emissions from forests, conserving forest carbon or enhancing forest carbon sinks.

Forest carbon management offers potential for some immediate financial benefits. However, so far only a few people have benefited from these opportunities. Accessing international financial mechanisms and voluntary carbon markets has proven to be difficult and cumbersome, due to the requirements to measure carbon and show both additionality and permanence of the carbon stock. This may improve as existing mechanisms are modified and new ones are developed. In addition, new international opportunities for financial and technical support for climate change adaptation are emerging.

1. Key climate change impacts on forest ecosystems

Reviews by Lucier *et al.*, (2009) and Fishlin *et al.*, (2009) on detected impacts, vulnerability and projected impacts of climate change on forests found that impacts varied across the continents with some forest types being more vulnerable than others. Impacts included increased growth, increased frequency and intensity of fires, pests and diseases and a potential increase in the severity of extreme weather events (e.g. droughts, rainstorms and wind). Human activities, including forest conservation, protection and management practices, interact with climate change and often make it difficult to distinguish between the causes of changes observed and projected. Deforestation and fires in the Amazon region, for example, form a vicious circle with climate change (Aragão *et al.*, 2008, Nepstad *et al.*, 2008), with the potential to degrade up to 55% of the Amazon rain forests (Nepstad 2008, Nepstad *et al.*, 2008).

In this section, observed and projected changes in climate and weather conditions and their impacts on forest composition, structure, diversity and processes for the major forest types in different parts of the world are discussed.

Forest conditions

Area

The area covered by forests is very likely to change under climate change, with shifts occurring between forest types due to changing temperature and precipitation regimes, while in some regions, forest area is expected to expand (e.g. temperate regions) and in others to contract (e.g. boreal, tropical and mountain forests). Such changes have been occurring in the past following the natural changes in temperature and precipitation that accompanied the different ice ages. Currently, however, it is very difficult to separate forest area change due to climate change from area changes due to other factors (Lucier *et al.*, 2009).

Globally, planted forests and natural regeneration have increased the forest areas in the United States, Europe, China, and some countries in Latin America and the Caribbean e.g. Chile, Uruguay, Cuba and Costa Rica (FAO, 2010). On the other hand, some countries in Africa, Asia and the Pacific and the tropical countries of Latin America continue to be subject to deforestation, mainly due to conversion to small- and large-scale agriculture and livestock while deforestation in the boreal forests of Siberia is mainly due to forest fires (FAO, 2009). Although the boreal forests are expected to move northward, temperate forests are expected to increase their area northward to a greater extent than the boreal forests, thus reducing the total area of boreal forests (Burton *et al.*, 2010).

In the future, it is expected that the combination of climate change, land use conversion and un-sustainable land use practices will interact. Changes in water availability are considered to be a key factor for the survival and growth of many forest species, although the response to prolonged droughts will vary among species and also among different varieties of the same species (Lucier *et al.*, 2009). Climate change will increase the risk of frequent and more intense fires, especially where changing climate is accompanied by lower precipitation or longer dry periods as in the boreal (Burton *et al.*, 2010), Mediterranean and sub-tropical forests (Fischlin *et al.*, 2009) and traditional land clearing practices as in the Amazon (Aragão *et al.*, 2008; Nepstad *et al.*, 2008). In the northern Atlantic region of Nicaragua, for example, Rodriquez *et al.*, (2001) found that the combination of the amount of rainfall during the previous three months and the average monthly temperature of the current month showed a strong relation with 64% of the fires between 1996 and 1999.

Although data are not conclusive, it is expected that frequency of strong hurricanes will increase in hurricane prone areas such as Central America and the Asia Pacific region. Hurricanes may destroy forest areas completely or cause heavy degradation. If left untouched, however, such areas will ecologically recover over time (e.g. Vandermeer *et al.*, 2000; Vandermeer *et al.*, 2001), albeit slow in terms of biomass (Mascaro *et al.*, 2005). The main effect is likely to be economic (infrastructure, crops and timber lost) and social (lost lives and livelihoods). Together with land use changes, however, the effects may be much longer lasting and devastating - degraded and young forests are easily converted into agricultural land and pastures (Williamson, 2010).

Health and vitality

Climate change may have profound impacts on the health and vitality of the world's forests. In some cases, vitality may increase due to a combination of a more favourable climate for growth and CO_2 fertilization. In most cases however, increasing temperatures favour the growth of insect populations that is detrimental to the health of forests (Lucier *et al.*, 2009). This is more likely to occur in forests dominated by few tree species or where specific temperatures or moisture levels control insect populations. For example, the spread of the mountain pine beetle, *Dendroctonus ponderosae,* in boreal forests, has been largely attributed to the absence of consistently low temperatures over a long period of time, which allowed an existing outbreak to spread across montane areas and into the colder boreal forests (Burton *et al.*, 2010). Similarly, Finland is expecting an increase in infestation of root and bud rots in their coniferous forests, due to the spread of a virulent fungus, *Heterobasidion parviporum,* favoured by longer harvesting periods, increased storm damage and longer spore production season (Burton *et al.*, 2010). In the tropics, on the other hand, increased warming reduces the life cycle of many insect pests, while at the same time increased fire damage makes trees more susceptible to insect attacks and vice versa (Lucier *et al.*, 2009).

Biological diversity

Species growth and survival depends for a large part on climate variables. Most species have a particular climatic range within which they grow best, are competitive and are able to adapt to slight environmental changes and respond to insect attacks, diseases and other adverse environmental and human influences. Many of the ecological processes that are needed for tree and other plant and animal species to live together are influenced by climatic conditions. The importance of climate for forest ecosystems and their composition and diversity is exemplified by the various global and regional vegetation classifications. The Holdridge ecological life zones (Holdridge, 1967), are limited by temperature, precipitation and humidity. Several researchers have attempted to estimate the impact of climate change on the forests of Central America, based on estimated shifts of the life zone boundaries (e.g. Mendoza *et al.*, 2001 for Nicaragua and Jimenez *et al.* 2009 for Costa Rica). Such studies, however, fall short of projecting real changes that may occur, since geographical shifts due to climate change are likely to occur on an individual species level, rather than on forest type level. This is mainly because some species will be able to adapt better to changing conditions than others, resulting in changes of composition of forest types, rather than geographic shifts of forest types (Breshears *et al.*, 2008).

In general, many species have a tendency to move to higher latitudes or higher altitudes (Rosenzweig *et al.*, 2007, Breshears *et al.*, 2008). Lucier *et al.*, (2009) in their revision of climate change impacts on forests, found reports of phenological changes in a number of species, with more and greater changes observed in higher latitudes. Common changes observed were changing flowering times and changing time of bud break, affecting productivity and carbon sequestration potential. Phenological changes observed in oak (Bauer *et al.*, 2010), apple and pears (Blanke and Kunz, 2009) and a range of 29 Mediterranean species (Gordo and Sanz, 2010), did not affect ecosystem processes other than bringing them a few days forward, although such behaviour was easier to predict in insect-pollinated species than in wind-pollinated species. Ecological processes such as pollination, flowering and fruit setting may be more affected in tropical systems, by changes in the phenological cycles because species interactions may be more complex and involve more than one species, while at the same time seasonality is not as clearly marked.

Forest ecosystem services and underlying processes

Following the Millennium Ecosystem Assessment report (Millennium Ecosystem Assessment, 2005), and forest ecosystem services are defined as the benefits that people obtain from ecosystems. While many ecosystem services can be identified and are often grouped into four broad types of services (Diaz *et al.*, 2005), only those services with well documented evidence of their management and their relation with climate change and human well-being are discussed in this paper.

Productivity

The impact of climate change on productivity varies according to geographic area, species, stand composition, tree age, soils (in particular water holding capacity), effects of CO_2 and nitrogen fertilization and interactions between any of 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 and Clark *et al.*, 2003). Some of the changes may be temporal, reverting once saturation levels have been reached. This is projected to be the case for water availability, where reduction of water generally reduces plant growth but in areas of water surplus may initially increase growth when waterlogging is being reduced. Similar reactions have been noted for CO_2 (Ollinger *et al.*, 2008, Clark *et al.*, 2003) and nitrogen fertilization (LeBauer and Treseder, 2008) as well as temperature increases (Reich and Oleksyn, 2008).

In general, productivity was found to increase with rising temperatures in most forest areas, including the Amazon, probably due to CO_2 fertilization. However, in contrast to temperate areas, production increases in tropical forests will be temporal and will decrease once CO_2 saturation levels have been reached. Some studies have already registered decreasing growth rates in tropical forests (Feeley *et al.*, 2007; Clark *et al.*, 2003). Water deficits over extended periods have also been shown to decrease productivity (Malhi *et al.*, 2008) and may be the cause for the declined productivity recorded by the studies above. Some authors argue that based on paleontological evidence this may not result in the forest dieback often mentioned in connection to expected changes in the Amazon region (Mayle and Power, 2008).

Natural disturbances often decrease forest area, but 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 and Nepstad *et al.*, 2008).

Carbon storage and sequestration

There is an important interaction between carbon storage and sequestration by forests and changing temperatures and precipitation. On the one hand, the more carbon is stored in forests; less will be in the atmosphere. Increasing this stock will thus contribute to reducing the rate at which the global temperature is increasing. This relation has become extremely important in the climate change discussions and many tropical countries are preparing themselves to reduce emissions and increase forest carbon stock in order to capture part of the funding pledged for GHG emissions reductions. In Costa Rica, recognition of this service led to the implementation of innovative financing mechanisms for forest management, planted forests and conservation during the mid-nineties (Sánchez Chávez, 2009). This has led to increased efforts to ascertain the extent and content of the existing natural and planted forests.

On the other hand, increasing temperatures, longer dry seasons and increasing CO_2 concentrations in the atmosphere in the long term, 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 and Clark *et al.*, 2003). Since carbon sequestration depends on productivity, all factors that affect productivity will also affect carbon sequestration (*see previous section*). In addition, in the short term, increasing temperatures may reduce carbon storage capacity, although the effect may vary depending on the season in temperate regions. Early spring warming, for example, has been found to increase carbon sequestration of terrestrial ecosystems, while early autumn warming increased respiration more than sequestration.

Soil and water protection

Forests have long been recognized as contributing to water and soil protection and in several countries this has been translated into systems that pay for these services (Postel and Thompson, 2005). Their positive influence on water regulation, however, is still discussed by foresters and hydrologists (Kaimowitz, 2001; Innes *et al*., 2009). The role of water regulation and soil protection may become increasingly important under climate change conditions. However, the capacity of forests to fulfil this role may be affected by the changing conditions. Reductions in rainy season flows and increases in dry season flows are of little value when total annual rainfall is low and significantly evaporated and absorbed by forests. In areas with frequent fog, the absorption of water by trees from the clouds (horizontal rain) may contribute significantly to the total amount of rainfall (Stadtmüller, 1994). The palaeoecological study of Amazon vegetation changes (Mayle and Power, 2008), indicated that in cloud forest areas, where trees often are submerged in fog, warming may cause the clouds to rise above the trees. This will reduce the potential for horizontal precipitation.

Multiple socioeconomic benefits

In some areas, climate change may increase growth, while in others decreases are expected. While the expected global increase in wood production may lower prices, benefitting consumers, the combination of lower prices and regionally differentiated effects on productivity will cause differentiated effects on timber harvest related income and employment (Osman-Elasha *et al*., 2009). The same authors project rises in timber production of up to 50% in all continents, except for Australia and New Zealand. However, most of this increase is expected to come from plantations, with increasingly shorter rotations and is therefore likely to be distributed unevenly amongst the continents (Osman-Elasha *et al*., 2009). In South America, where greatest increase is expected, current plantation production is concentrated in southern Brazil, Argentina, Uruguay and Chile. Natural forests are found in the tropical regions of the continent, where forest dieback may decrease timber production.

Harvests of non wood forest products (NWFP) have three major functions: provision of part of the daily necessities of forest dependent people, off-farm income and a safety net in times of adverse conditions for agricultural production. Osman-Elasha *et al*., (2009) suggest that climate change will have impacts on the productivity of NWFPs and that NWFP users will largely be impacted through increased pressure on forest products from people that look for emergency supplies or alternative ways of income. The latter is likely to occur in areas of high poverty, high dependence on NWFPS and increased frequency and intensity of extreme climate events and other natural disturbances, such as pests, diseases and fires. The impacts of climate change on the provision of these products and the subsequent socioeconomic effects, however, require more studies.

Climate change impacts on cultural and recreational services of forests have also been little studied and are difficult to measure, in particular for those services that by themselves are difficult to measure. Osman-Elasha *et al*., (2009) report some studies on well defined recreational services, such as skiing in mountainous areas, where skiing at lower altitudes is likely to be affected by temperature increases. Recreational values placed on forests are usually local and unfortunately in most countries no reliable climate change projections have been made at such a scale. The same authors indicate that the effect of climate change on forest biodiversity and structure in Africa and the subsequent effect on attractiveness for tourists of many of the national parks need to be further studied.

2. New challenges, opportunities and constraints posed by climate change to forest management

Climate change poses new challenges, opportunities and constraints for forest management. These include changes in:

- the natural environment, which is the basis for forest management;
- the socioeconomic environment, particularly where local people depend heavily on the goods and services from forest ecosystems;
- international and national policies and legislation, such as REDD+ agreements, land tenure agreements;
- the markets, such as the carbon market, and;
- relations between different stakeholder groups, exemplified by the increased recognition of the tenure and intellectual rights of Indigenous Peoples.

These changes pose challenges for forest users. In some cases, they may be opportunities while in other cases they may constraints. This will depend on the user, type of use, geographic location and the current local socioeconomic and political situation. The possible implications of these changes for the management of forests for different objectives will be discussed in the following subsections, following the seven thematic elements for SFM endorsed by FAO.

Changes in the natural environment

Strengthen adaptive capacity of forests

Most changes described in previous section negatively affect forests and many of their plant and animal species. In addition, they may negatively affect the availability of other resources, necessary for species survival. Current forest composition and structure are however, the result of past changes in climate and shows that forests and their species have an inherent capacity to adapt to change. The main differences of current climate change with historic changes are the increased rate of these changes and the degraded and fragmented state of the remaining forests, which reduces the capacity of the species and ecosystems to adapt (Noss, 2001). The challenge is to help species and ecosystems to adapt to climate change while at the same time ensuring that ecosystem services are maintained. This will require the identification of the changes to which the forest will need to adapt.

Locally, changes may be disastrous, unless climate, ecosystem and species changes are accompanied by adjustments in the local social and economic systems. For example, increased occurrence of severe fires will require greater collective action to prevent fires as well as improved weather and fire danger forecast services (Brondizio and Moran, 2008). Companies producing furniture of high value species from natural forests, whose natural regeneration under changed climate conditions has become increasingly difficult, may have to change geographic range for their inputs, or change to other species and/or other processing procedures. Communities and private landowners depending on local forests may have to change livelihoods after severe hurricane damage.

Nationally or at the landscape level, changes may be slower and less disastrous in the short term. New challenges include the identification of those species groups and ecological processes that are essential for the most important ecosystem services. This would include in most cases identification of water catchment areas (hydrogeology) and the role of forests in maintaining water quality and quantity. It will be important to increase the probability that changing ecosystems will continue to provide the important services and goods. In particular, ecosystems in geographic locations at the extreme limits of climatically well-defined areas, such as mountainous forests, rangelands and boreal forests, are likely to be severely affected and may disappear. Some authors suggest that maintaining functional diversity and composition will preserve ecosystem services (Didham *et al.*, 1996 and Tilman *et al.*, 1997), while others found that different functional groups will react differently to environmental changes (Domingues *et al.*, 2006), indicating that climate change may favour some functional groups over others. More research is needed however, to identify those functional groups essential for the desired ecosystem services and goods in particular areas and to understand how these can be conserved and protected.

Reduce risk and intensity of pest, disease and fire outbreaks

Reducing the climate induced risk of pests, diseases and fire outbreaks, in particular, in dry areas and less diverse forests will be a major environmental challenge. Breeding of more resistant or more resilient varieties is a medium to long-term solution for plantation species, although, that introduces new risks because strengthening the adaptive capacity of a species for one trait may weaken it to other traits. Identifying species for their "realized fitness" (Bradshaw *et al.*, 2011) - for example, varieties of a species that survived insect attacks, diseases or fires, similar to the expected events in a particular region - and then facilitating their migration to the area of interest, may be another strategy. In both cases, identification of the traits that will increase resistance or resilience will be important as will be replicating those traits over generations and successfully introducing the species or varieties in the area of interest, without introducing new problems (such as undesired invasion).

Predicting future changes in pest and disease outbreaks and adjusting management accordingly (Dukes *et al.*, 2009 and Waring *et al.*, 2009) is another option, which requires the development and validation of models that reliably predict impacts under different climate and management scenarios. A further option is the identification and implementation of forest management systems that are known or thought to reduce the risks of pests, diseases and/or fires.

While there are several well known means to protect forests and plantations (FAO, 2011; Forbes and Meyer, 1955; Isaev and Krivosheina, 1976; Faccoli and Stergulc, 2008; Wermelinger, 2004; Bunnell *et al.*, 2004; Suyanto *et al.*, 2002; Mori, 2011; Griscom and Ashton, 2011; Syphard *et al.*, 2011; Mazour *et al.*, 2010; González-Cabán, 2009; Van Lierop, 2009; Martell, 2007), in many cases these are not applied for a variety of reasons (González-Cabán, 2009), or are not applied to those forests most in need (Pressey *et al.*, 1996; Pfaff *et al.*, 2008). The challenges are to identify and address the reasons for the lack of application of management techniques and to adjust management options to the threats in a participatory, socially and economically acceptable manner (Orstrom and Nagendra, 2006).

Changes in socioeconomic environment

Risk of migration into forest areas

Climate change will affect all people but in particular, rural people that depend on nature for their livelihoods, and poverty stricken communities in the urban-rural interface that are often subjected to the consequences of extreme weather events. Climate change is expected to change the aptitude of lands for specific crops, cause problems of droughts, fire and flooding and may drive many people from their lands. These people are likely to either go to cities to look for jobs, often adding to urban poverty, or to other rural areas to look for other lands where they may be able to continue their agricultural livelihoods or find employment in the agricultural sector (Gemenne, 2011; Martin, 2010; Magrath and Sukali, 2009).

The surge of interest in fuels from biomass (e.g. corn, sugarcane and oil palm) adds another dimension to this migration. The purchasing of land, often based on speculation, in the hope of selling later for higher prices to investors interested in biofuel production, may cause migration. The expected high incomes from biofuels may also motivate landowners to convert their forests into energy plantations (Grau and Aide, 2008), oftentimes in an unsustainable manner. On the other hand, if well planned, biofuels could also help avoid or reduce migration by providing off-farm employment (Jain *et al.*, 2011).

Forest use values, even in the case of the most successful enterprises, will not be able to compete with oil palm or other energy crops in those lands suitable for the crops. Legal definition of user and owner rights of forest areas and the mechanisms to defend those rights will be important elements of strategies to prevent unauthorized entrance into forests. Market mechanisms that restrict trade of products from companies that do not show social and environmental responsibility in their production and purchase policies may be another strategy. An individual forest user or owner will find it difficult to influence legislation, their implementation or the way that markets function. Collaboration with other stakeholders, neighbours, value chain members, and state administrators will be essential to the development of adequate measures to reduce the conversion and degradation of forests. Forest users and owners, however, have a longstanding tradition of independence and in the past have not shown tendencies to such collaboration. Lack of trust (often justified), has often hampered relations between different stakeholders in the forest and environmental sectors. Building sufficient trust to facilitate collaboration may be the biggest challenge of all for future forest management (REDD-Net Bulletin Asia-Pacific, 2010) and needs the collaboration of all actors involved.

Greater demand for forest ecosystem services by local people

Climate change is expected to increase the frequency and intensity of extreme weather events, such as hurricanes, torrential rains and droughts. Rural people often depend on emergency supplies during or just after such events. Forests, in many cases in the past, have provided such emergency supplies or safety nets (Osman-Elasha *et al.*, 2009) e.g. wood for construction and repair of houses, woodfuel for cooking and fruits and other food to replace the lost crops. The need for these safety nets will further increase when climate change increases the loss of crops. Indigenous groups are often vulnerable to extreme events, especially those events that restrict access to the outside world and markets. However, in such cases, they can usually find sufficient emergency supplies from within the forest until access is restored. In addition, more people have become aware of the different ecosystem services and want to use such services even under non-extreme weather conditions.

Forests as regulators of water quality and quantity have become ever more important, in particular, in areas with frequent droughts and/or frequent torrential rains that may cause erosion, sedimentation and flooding. In Central America, this function may be one of the main reasons for forest protection or restoration by private landowners even though it is possibly based on an erroneous perception of the benefits of the forest, since such functions may not be beneficial in some climate and soil conditions. The impact of climate change on this ecosystem service, however, is still not very well understood, since different species, different environmental and geological settings and different socioeconomic conditions may affect the response of this service to climate change (Imbach *et al.*, 2010).

Land tenure and other forest right issues

Deforestation and forest degradation in tropical and some of boreal forests are serious problems that contribute to the emission of greenhouse gases as well as to the fragmentation of forests. Deforestation and degradation have a series of direct and underlying causes (Kanninen *et al.*, 2007; Geist and Lambin, 2001), but none of these can be resolved if land and forest tenure are not clear or are not enforced (Corbera *et al.*, 2011; Nawir *et al.*, 2007; Walters *et al.*, 2005; Suyanto *et al.*, 2002b).

State land is more frequently subject to conversion into agricultural land than privately owned land. Privately owned and concession forests, however, are increasingly coming under pressure, especially in countries with policies that recognize traditional rights or favour the rights of community inhabitants to their surrounding forests. In the Amazon region, community lands also receive increased pressure, possibly due to the regional infrastructural plans (IIRSA), speculation of future forest values under new international agreements on climate change (REDD+), investment in bioenergy, the relatively large size of many community lands in relation to their population and the lack of financial and human resources to secure their borders. Since many of the areas with land and forest rights concerns are in remote areas and refer to areas where people may have conflicting interests, regularizing these rights has been a major challenge in the past. Some progress has nevertheless been made in Latin America (Sunderlin *et al.*, 2008; White and Martin, 2002).

Changes in policy environment

REDD+ expectations

Probably one of the more notable short-term changes in the policy arena is the discussion of GHG emissions reduction through REDD+ and management, conservation and restoration of forest carbon stocks. Large sums of money have been pledged against the demonstrable reduction of GHG emissions through REDD+, but so far, no international agreement has been reached on emissions reduction targets for developing countries. Further, in many pilot projects, measurable results have been interesting but financial benefits limited (Harvey *et al.*, 2010). REDD+ expectations are manifold, depending on the interest group. Some of these expectations are justified, others not, and most are probably too ambitious. Implementation of REDD+ strategies will have to deal with most, if not all, of the challenges mentioned in this chapter. At the same time it will require the implementation of a monitoring system, the extent and detail of which has not yet been agreed upon. While this has serious implications, the current (international and national) political environment is set to enable projects and countries alike, to meet at least some of these challenges. For the forest manager much of the challenge lies in adjusting management practices in favour of carbon accumulation, while at the same time maintaining biodiversity, recognizing the rights of indigenous people and contributing to local economic development.

Changes in legislation

In Latin America, many countries implemented new forest legislation in the period between 1995 and 2000. While in some countries this was based on a thorough analysis of the forest sector, in others it was more in response to different pressure groups and based on changes in neighbouring countries. In some countries (for example Costa Rica), new legislation was relatively successful in achieving the objective of forest conservation (MINAE, 2002), although reducing forest use for timber production considerably (Louman, *in print*). In others, it has been difficult to implement new legislation if unaccompanied by other measures and if the process was not participatory and consultative (FAO, 2005; Walters *et al.*, 2005). More recently, countries have realized that they have better results when their new legislation is developed using more participative processes (for example in the DRC and Honduras). However, these processes are too young to be able to assess the true success in terms of increased implementation of legislative requirements.

Climate change will increase the challenge of designing and implementing new legislation that considers new international agreements, conflicts of interest in forest areas, as well as the need for coordination with other sectors. This may involve legislation on land and forest tenure, indigenous rights, the production of fuels and land use planning including restricting the access and use of certain areas or of some species, due to the risk of climate change impacts or the need of soil and water protection or maintenance of biological corridors. In revising forest legislation, it is important to consider all related legislation, so that, for example, legislation or policies oriented at increasing forest area on private land is not nullified by policies or legislation that define forest land as ‘un-used’ or ‘luxury possessions’, taxing them relatively heavily or even threatening to expropriate the owners.

Changes in market relations

Social responsibility requirements

Concerns for sustainable development, for the deterioration of the environment and of social relations, as well as for the negative effects of climate change at different scales are influencing market decisions. This can above all be noticed in agricultural product markets, where buyers are looking for products that meet specific environmental and/or social standards. Some banana plantation owners that export to the European market, for example, have started to invest in forest land for conservation and carbon emissions compensation. New standards have just recently been developed to monitor and evaluate carbon dioxide equivalent emissions from livestock farms in Costa Rica, while the COOPEDOTA coffee cooperative was recently declared carbon neutral. These new developments pose interesting opportunities, more research is required to determine how these mechanisms can be used to improve the maintenance of other ecosystem services (such as water regulation and biodiversity maintenance), strengthen the adaptive capacity of natural and human systems and complement conservation and sustainable use of the existing forest areas within the agricultural landscapes.

Opportunity costs of land use

Meeting REDD+ expectations has much to do with being able to identify the opportunity costs of local actors when they choose forest conservation and management rather than other land uses. Many of the REDD+ cost analyses are based on compensation for lost opportunities (Angelsen *et al.*, 2009; Stern, 2006), although it has been found that forest conservation on private lands does not only occur for financial reasons (Morse *et al.*, 2009; Wünscher, 2008). If lands surrounding forests have high opportunity costs, there is the likelihood of increased pressure to convert those forests to the adjacent land use in order to make them more profitable. Opportunity costs may vary due to variations in market prices of the crops cultivated, government policies that subsidize agricultural inputs or the exportation of the outputs, or policies favouring the production of biofuel. The forest user or owner does not easily influence these factors. As a group, in particular, if acting within the framework of REDD+, it may be possible to influence legislation, reduce the unequal treatment of forests as compared to agricultural crops, thus making forest management more competitive with other forms of land use.

Uncertainty and risk management

Climate change projections for the future involve a series of uncertainties. It is still not sure what emission scenario will best reflect reality, how these emissions change climate, in particular in relation to the distribution of precipitation or what other factors may play a role in influencing local vegetation and how local vegetation will react to climate and other factors. Thus, forest management for climate change has to deal with a range of uncertainties. The challenge is to reduce those uncertainties and to design management systems that can deal with unexpected changes. Uncertainty and risk management options may involve monitoring systems (e.g. climate, biodiversity, production, and social impacts), early warning systems, working groups that analyze the implications of data obtained through monitoring, mechanisms dealing with risk of income loss, appeal systems for unpopular decisions as well as free prior and informed consent of indigenous and local communities. Flexible adaptive management approaches need to be a part of any management strategy that involves risk and uncertainty. Such strategies will need to include a set of tools, rather than one specific approach, to be able to switch from one to another tool, depending on local conditions, changes in those conditions, and success of already applied tools (Millar *et al.*, 2007).

3. Forest management options for climate change mitigation & adaptation

The previous sections review the potential effects and significance of climate change on the forest sector. These impacts have varying consequences and are dealt with differently by forest managers. In this section, the possible operational options available to forest managers for addressing climate change mitigation and adaptation are assessed. In addition, the extent to which these options are being applied by forest managers is discussed, with the help of case studies. These examples, although not necessarily due to climate change, give good indications of what managers perceive to be good solutions to potential future changing climatic conditions.

Monitoring

Forest monitoring is very useful to detect changes due to climate change, natural disturbances or human activities. It has become a requisite in the context of climate change mitigation in particular, in relation to deforestation and forest degradation. Due to the potential benefits that accurate carbon monitoring may bring within the REDD+ framework, monitoring has developed greatly over the past few years and requisites on accuracy and acceptability have increased.

For monitoring in general to be successful, it needs to have clear objectives, be as simple as possible, and benefit the people that invest time and/or money in it. However, many times the objectives may be clear, but the activities that are needed to meet those objectives may be vague. This may be due to lack of experience or lack of certainty on how climate will change and how this possible change will affect different components of the forest and forest management. A tendency exists to want to monitor everything that might possibly change, resulting in impractical and expensive monitoring proposals. As a result, monitoring for the impacts of climate change on the forests and people related to the forest is still just emerging.

Monitoring helps us to identify changes and evaluate tendencies. Monitoring does not necessarily tell us the reason for these changes and tendencies, unless previous research has established such causal links. The next step would therefore be to analyse whether such changes correspond to changes in climate characteristics and then, to analyse whether such tendencies are negative or positive for the forest and the forest managers and whether actions can be taken to reduce the negative consequences and increase the positive ones.

Current discussions on the implementation of REDD+ are occurring at the national level, however most of the monitoring experience has been obtained at the forest management unit level. While monitoring needs at these levels differ, they are highly complementary and any carbon monitoring system should consider linking these levels. It is very important to include all stakeholders to ensure agreement on the methodology and the variables to be monitored. The involvement of local actors has been shown to have two advantages; it is cheaper and creates greater ownership of the monitoring results (Skutsch *et al.*, 2009).

In spite of the importance of monitoring for SFM and for preparation of responses to climate change, it still is not a common practice. Particularly in developing countries, few forest managers have the resources (human and financial) to implement these assessments.

Monitoring of changes

Adaptation of forests requires in the first instance the identification of the changes that may occur and to which adaptation may be necessary or desirable. Although in general terms forest change scenarios can be developed based on global and regional climate change projections (Fischlin *et al.*, 2009; Jimenez *et al.*, 2009), the exact changes that will occur are not well known. There are several reasons for this uncertainty; the uncertainty in the climate change models in general, the scale at which climate change projections are made, the inherent adaptive capacity of species and the communities they are in and the effect that interactions between species may have on adaptive capacity. In some areas, the changes that have been projected are drastic. The northeastern Amazon, for example, may lose most of its forest cover because of massive forest dieback due to droughts, giving rise to savannah vegetation (Malhi *et al*., 2008). However, the rate of change and the exact result is not that clear (Mayle and Power, 2008). Other areas may follow suit at different rates and with different results. It will be difficult for forest managers to react to these changes, especially if it is not clear when and how these changes occur.

Adaptation strategies will need to include monitoring systems on climate, vegetation, fauna and essential non-biological components of the forests such as water availability. Without such monitoring systems, the forest manager will be grappling in the dark when making management decisions. In forestry, such monitoring systems are important, particularly because of the long time lapse between management actions and forest response. For this reason, permanent sample plots (PSP) are an integral part of SFM. Their main contribution to SFM has been a better understanding of the dynamics of forests and plantations. PSPs have been used for stock-taking (both at a national scale and in continuous forest inventories), for monitoring of changes in managed and unmanaged forests (e.g. in certified forests to monitor changes in species composition and structure), and for research purposes (e.g. the effect of silvicultural treatments and harvesting on species composition, structure and biodiversity). PSPs are less useful to measure changes in the diversity of fauna, impacts of forest operations such as harvesting and impacts on ecosystem services that go beyond the forest plot boundaries (for example water flow).

In countries that have long-standing experience with PSPs and a good network of meteorological stations, PSPs may provide a good contribution to the analysis of the effects of climate change on forests. While PSP are good instruments to detect changes at the stand level, forests are also influenced by changes that occur on a landscape level, e.g. water quality affected by sedimentation. To detect such changes, a combination of remote sensing techniques and a network of PSPs is probably the most appropriate strategy: remote sensing to detect changes in forest areas, and PSPs to detect changes in forest quality. Since remote sensing images and their interpretation for forest management is relatively costly for the forest manager, such monitoring is best carried out by organizations or associations that are responsible for larger areas or a group of stakeholders. This will require, that all potential users of the monitoring information agree on a common set of variables that are useful for forest management decisions and should therefore be monitored (Peterson *et al*., 1999). An important part of monitoring systems is the database and processing of the data. This usually requires major investments in human resources but some companies have been able to develop their own computer hard and software that allows for quick data storage and analysis.

Box 3.1. Permanent Sample Plots as a strategy to monitor changes in the forest due to climate change

In Costa Rica, research institutions have formed a collaborative network with the intention to standardize the way they will be registering changes in the forests due to changing climate or in response to management activities oriented at fulfilling national policies. 13 institutions with over 500 permanent sample plots have decided to select those plots that are best representative of the different forest types, cover a range of climatic conditions (in particular where climate change is expected to have greater effect) as well as a range of management systems. They also work together in identifying the measurements that should be made and that will be useful for forest managers. Currently they are working on the protocols that will allow sharing the data while at the same time respecting intellectual property rights. Because private forest holdings are small, and no governmental network of PSP exists, such inter-institutional collaboration is the only way for the different forest managers (government, community and private forest holders) to have access to information on changes in the forest that may become vital for future forest conservation and management decisions.

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Monitoring of animals

The techniques used monitor animal populations, particularly the larger mammals, depend on the objective of sampling. More local research is necessary to identify the techniques and variables to be sampled in specific cases (e.g. for a particular species in a defined region). Climate change can shorten the life cycle of insects, increasing their reproduction rate and the risk of infection and damage. Traps in sampling points can help to detect rapid increases in population sizes. The traps will need to be specific for the insects to be monitored, have appropriate bait and be placed at the right position in the forest. Turchin and Odendaal (1996), found that one funnel trap, used to trap southern pine beetles in the united States, were good for covering an approximate area of 0.1 ha. Some insects are more ground related (e.g. dung beetles) while others (e.g. butterfly families) may fly in open or closed forest areas (Aguilar-Amuchastegui *et al.*, 2000). Although these latter insect groups have not been related to pests, they have been successfully used to identify changes in forest structure and composition related to fragmentation and tree harvesting, and may be useful to detect forest changes due to climate change. Specific dung beetles may be related to specific mammals and butterflies have been related to openness of the forest and may be an indication of dieback. Further research is needed to fully understand these relationships. Larger animals may be trapped (as in the case of small rodents), or counted visually using walking transects (Steele *et al.*, 1984). Animal tracks may also be used as an indication of the presence and abundance of species. However, care should be taken that sampling density is sufficient to formulate robust conclusions. Steele *et al.*, (1984) concluded that three repetitions of a 2 km transect was sufficient to determine species abundance, richness and diversity of large animals, but it was more difficult to estimate small mammal richness and diversity. In general, design of a monitoring system requires expert knowledge, but local communities can be trained as para-taxonomists to implement the monitoring.

Due to the need for additional information on species behaviour and preferences, as well as the relatively high time investments needed for animal monitoring, it is important to identify, as early as possible, those animals (and plant species alike) that are more susceptible to climate variations. Abundant animals may be easier to monitor, but many of them may also be less susceptible to changes in climate and the environment. Usually the species with a small range and short generation time are more responsive.

Forest fire monitoring

Monitoring of forest fires contributes to our knowledge on the extent of deforestation and forest degradation. Such monitoring is traditionally done through patrolling forest areas and operating watchtowers. The development of remote sensing techniques has made it possible to come to ever more accurate and timely information on forest fires, above all in large uninhabited areas. Laneve *et al.*, (2006) estimate that if images can be obtained at a sufficient spatial resolution to detect 1500 m^2 fires at 30 minute time intervals, this will be sufficient to reduce the number of large fires in the Mediterranean forest of Italy. For small forest land holders and many communities, such technology is not available and even the construction of towers may be too high an investment. Patrolling, however, has shown to be an effective way of forest fire prevention in community forests in Guatemala. During the last decade several proposals have been made to set up fire detection systems using wireless sensors (Hefeeda and Bagheri, 2008), but most of these have not emerged from the experimental phase, possibly due to costs and the problem of maintaining the network.

Box 3.2. Community monitoring

In **Nepal** communities defined their own biodiversity indicators based on the discussion of observations made during forest walks. Together with group discussions and resource mapping, monitoring contributed to a learning process on biodiversity, changes observed and the possible causes for those changes (Lawrence *et al.*, 2006). In **Mexico**, in the context of the Payment for Environmental Services scheme for biodiversity maintenance, communities have been trained to make observations on species occurrence in a manner that contributes to national assessments.

Strengthen capacity of forests to respond to climate change

The adaptive capacity of forests, for the purpose of this document, is understood to be the inherent ability of the forest to adjust to changing conditions, moderating harms and taking advantage of opportunities (Locatelli *et al.*, 2010). Thus, strengthening of the adaptive capacity is oriented at increasing the resistance or resilience to changes but may also include adapting the forest to new conditions by facilitating changes in the system (e.g. by species introduction). In general, strengthening the adaptive capacity of forests aims to maintain, restore or enhance forest area, biodiversity and forest health and vitality. Many of the actions oriented towards mitigation of climate change through REDD+ have a strong potential for synergies with actions oriented at strengthening the adaptive capacity of forests, in particular if such actions consider ecological safeguards, such as biodiversity conservation.

Experiences in strengthening the adaptive capacity of forests to climate change have been more widespread in plantations and agroforestry systems. These systems tend to have a simpler structure and composition that makes it easier to detect changes due to climate change and to design and implement adaptation-strengthening mechanisms. This is much more difficult in complex natural forests, in particular in the tropics. However, because of their simplicity, these systems may also be more vulnerable and therefore the need to look at adaptation options is greater. Interestingly, several of these adaptation activities are oriented towards making these (agro) ecosystems more diverse (see recommendations by Innes *et al.*, 2009).

Maintaining forest area

Larger forests usually have greater species diversity and cover a greater variety of sites, thus reducing the risk of losing the whole system if climate change negatively affects several species or specific site conditions. Forest management appears to be the solution; both well-managed protected areas and well-managed community and private forest concessions in Guatemala and the South of Mexico have shown to be more effective in avoiding deforestation, fires and forest degradation than areas poorly managed areas (Bray *et al.*, 2008). This probably goes beyond purely economic considerations. Land and forest tenure, recognizing the benefit of maintaining forests and joining forces with other forest managers are all important requisites. Size of forest area also seems to be important, for both individual landowners and community or multiple owners. Ecologically, larger forest areas show less edge effects, while from the management point of view, larger sizes allow for economies of scale.

Managing natural forests often is recognized as a claim on that forest. If good relations are held with local people, such claims are well respected. Owning forest but not managing it, has often resulted in unauthorized entry by third parties for the extraction of timber and NWFPs, or for conversion to agricultural land. Managing the forest but not entertaining good relations with the neighbours has often resulted in forest use conflicts, at times ending up in armed conflicts or burning of parts of the forest estate. Such relations are more important in large forest tracks, since in these it is harder to establish continuous human occupancy.

Good forest management normally includes fire, pest and disease management. Of these, fire management may be the most significant in maintaining the forest area, although serious pests, such as the mountain pine beetle in pine forests in North America, may also contribute to substantial forest loss. Managing the forest may be costly and income from the sale of one or more of its products may not off-set the extra cost of management. However, often, cost-benefit analyses compare conventional operations (without much strategic planning or considerations for biodiversity or forest dependent communities) with managed operations. From a private forest owner's point of view, this may be reasonable, but in practice, this approach has been used to justify continued conventional harvesting operations, giving the forest sector a poor image and increasing the pressure on governments to impose stricter regulations. In countries with greater willingness of the private sector to participate in improving forest management, a series of alternatives were found to either make forest management attractive or propose other forest-based income solutions. Usually this was done by a carrot and stick approach: if a forest manager does better than the legislation requires, they receive subsidies, discounts on taxes and are a preferred provider of specific ecosystem services. While these approaches in theory seem to be very promising, in practice they have not had the expected outcomes. This is partially because of the high financial and administrative cost to actually obtain the carrots and because forest owners and managers were not aware of the existing opportunities.

Management of forests, therefore, should go beyond the mere planning of protective or productive activities and not depend on one single form of financial income. Forest managers need to be informed and aware of local, national and international opportunities for income generation. New opportunities may be through tax or fee discounts for good forest management (as the case of harvesting fee discounts for certified forests in Peru), payment for environmental services (e.g. Costa Rica and Mexico) or niche markets (e.g. markets for specific NWFPs and carbon). Due to the relatively limited demand of these above mentioned products and services and with only a few exceptions (e.g. Brazil nut gathering in Bolivia, Stoian, 2004), none of these have been able to single-handedly pay for management and protection of large natural forest tracts. Only where combinations of products and services were obtained has management of natural forests become a serious land use competitor.

New opportunities may also work for forest plantations, where payment for environmental services, such as carbon sequestration, may at least partially off-set the initial establishment costs. However, selling sequestered carbon at the end of the rotation has little effect on the overall profitability of plantations, due to the low carbon price and high interest rates. The present value of these future sales is very low and rarely will change a non-profitable exercise into a profitable one. Selling less carbon earlier on during the rotation, or shortening rotation length, are two options that may make timber plantations more attractive. Establishing tree plantations not for timber, but only for carbon or other environmental services, as yet has to show its profitability for the forest owner or manager and is usually only accomplished where the forest owner or manager also garners important non-tangible benefits from those forest.

Conserving biodiversity

Maintaining forest area is of course a good means to maintain a certain level of biodiversity. However, as can be seen from some countries, increasing forest area does not necessarily increase biodiversity nor does it necessarily mean that old forests or undisturbed forests are maintained. In many countries, reduction of net deforestation figures is at least partially due to compensatory measures, such as natural regeneration and plantations (FAO, 2010). Although depending on how these new forests are being managed, and how close they are (in time and space) to the original natural forests, these usually do not have the same species composition and biodiversity as the lost natural forests. In terms of capacity to adapt to climate change, the change in species composition may sometimes be an advantage, if new species are better adapted to changing conditions. More problematic may be loss of diversity. Loss of diversity will make forests more vulnerable to changes, since they will not have the rich gene and species pool from which to select for the new conditions. In this respect, care should be taken of the trade-offs between mitigation and adaptation objectives; too great an emphasis on management for carbon may reduce structural and compositional diversity, thus reducing the system's inherent adaptive capacity (Amato *et al.*, 2011).

A noted change in forest management in the light of climate change has therefore been an increased interest in maintaining or increasing diversity of the forests. Mixed species plantations, use of a larger number of clones and reductions in the scale of harvesting operations have been implemented as measures to maintain or increase biological diversity. These same measures are now receiving more attention because of their potential benefit in preparing forests for climate change. In addition, literature (Piotto, 2008; Erskine *et al.*, 2006; Kelty, 2006; Nichols *et al.*, 2006) suggests that the potential yield increase from appropriately selected species mixes will more than outweigh the additional costs that may be involved in mixed tree plantation establishment. The use of nitrogen fixing tree species as part of the mix, in particular in degraded lands, is beneficial for overall growth rates (Piotto, 2008).Reducing the scale of harvesting operations is one way of increasing the possibility of ecological connectivity between forest patches. Plantation establishment is also an important measure that may achieve this (Biringer *et al*., 2005) as does planting of trees outside the forest (Louman *et al*., 2010).

Although some practices are being adopted and theoretically will contribute to maintaining biodiversity, there is still a need for further research. For example, we do not yet know how much biodiversity change will cause a major and irreversible change of forest types or even ecosystems. As mentioned previously in this document, some authors suggest that maintaining functional diversity may be sufficient. However, it is unclear how susceptible diversity will be to climate change, if, for the different functions, the number of species that provide diversity function is strongly reduced. It is also unclear how species will react to climate change, by themselves, in combination with other species and in combination with a number of environmental and human factors. Continuous monitoring of the forests is critical to providing insight into these interactions.

Maintaining forest health and vitality

The main threats to health and vitality are pests, diseases, fires and extreme weather events. In addition, diversity usually strengthens health and vitality and therefore the actions mentioned above to maintain or enhance biodiversity, also are useful for maintaining health and vitality. A number of silvicultural techniques have been developed for maintaining health and vigour of a stand. Removing old, poorly formed and damaged trees, for example, reduces the risk of spreading diseases and pests, although at the same time it may reduce diversity and thus increase the susceptibility of forests to diseases and pests. Applying such treatments requires knowledge of the specific risks related to individual tree species and the potential benefits of maintaining poorly formed trees in the forest. Using harvesting residues on the forest floor may increase availability of nutrients for the remaining trees, thus increasing vigour, but may add to the fuel load and therefore increase fire risk. Nevertheless, timing of use (beginning of wet season) may increase the benefits and reduce the risks.

In plantation forests, a reduction of old growth and an increase in the relative presence of young stands, enhances the general health and vigour of the forest from the point of view of timber production in the medium term. Again, however, it reduces diversity, thereby reducing the adaptive capacity of the forest to externally driven changes. The decision to reduce such growth in favour of young stands needs to be taken in consideration with local conditions and management objectives.

Reducing risk and intensity of damage

Reducing the risk and intensity of pests, diseases, fires and hurricane damage, along with managing the hydrological cycle, will become major concerns for many, if not all, forest managers under changing climatic conditions. Due to the complexity of measures that may have contradictory effects, there is the tendency for integrated management practices; for example, combining insect control with monitoring exercises and implementation of management practices that reduce susceptibility of the forest to insect attacks. Such practices include those treatments that help maintain the vitality of the forest, including timely thinning and species mix (Clarke, 2004). For most regions however, few comprehensive management plans exist, and in most cases, plans emphasize monitoring and combating pests and diseases, rather than preventing them (FAO, 2009b).

Box 3.3. Pine beetle management in Central America

After the devastating outbreak of bark beetles in Central America around the turn of this century a major effort was done to strengthen technical capacities for the prevention, mitigation and combat of beetle outbreaks in the different affected countries. FAO was involved through a Technical Cooperation Program (TCP), initiated in 2002. Different species of *Dendroctonus* were responsible for the mortality of trees and different pine species were affected in different manners. Geographic location and altitude appear to be factors that limit the range of the different *Dendroctonus* species, with D. frontalis being the species with an apparent wider range, from the lowlands to the highlands and from the southern limits of natural pine stands in Nicaragua to the northern limits of the region in Guatemala. Based on the analyses done during the TCP, the following recommendations were made for management of *Dendroctonus* (after Clarke, 2004; Billings *et al.*, 2004).

- Compile basic biological data on *Dendroctonus frontalis, D. adjunctus, D. parallelocollos, D. mexicanus.*
- Confirm the existence of a new species in Belize. This needs to include ecological range, hosts, strategies for attacking the hosts, bate-specifity, etc.
- Utilize communities and other agencies in detection of infestations. This will need production of pamphlets to raise awareness on beetles and recognition of their damage patterns.
- Develop a hazard-rating system for forests that allows early warning of population build-up.
- Include protected areas in the monitoring and hazard reduction exercises. Although cutting infested trees will have negative impacts on the protected areas, not doing anything to suppress the infestation may have much bigger negative consequences (compare the mountain pine beetle spread in Canada in the last few years).
- Strengthen ability to prevent attacks, for example by studying correlation between stand conditions and incidence of bark beetle attacks.
- Develop strategies for marketing and processing of infested timber that prevent great price fluctuations. Price drops after infestations have been a great disincentive to do salvage harvesting, reducing the efficiency of suppression measures.

Rojas *et al.*, (2010) confirm the potential link between climatic factors, conditions of the forest and occurrence of *D. frontalis* in Honduras. Average temperature during the dry period, climatic anomalies, and the occurrence of forest fires were found to be reasonable predictors of epidemic attacks of *D. frontalis*. According to (Billings *et al.*, 2004), integrated management should include activities such as thinning to reduce stand densities; removal of infested trees and harvest of those trees that show signs of weakness (old, affected by fires, wind etc.). On site felling may be effective for *D frontalis*, reducing the survival of the beetle. Underbrush fires, if of low intensity and in young stands, may increase vigor of the trees and thus increase resistance to the bark beetle. But when fire intensity increases, the stands are too young or too old, it may also contribute to weaken the trees further and increase beetle attacks.

The example of pine beetle management in Central America (Box 3.3.) shows how management oriented towards the prevention of fires may also reduce the risk of insect pests.

Integrated fire management in forests has been promoted in many countries and by international and national agencies alike. The proceedings of a 2009 seminar in California summarize many of the experiences and achievements to date (González-Cabán, 2009). Martell (2007) defines forest fire management as: "*getting the right amount of fire to the right place at the right time at the right cost*". Integrated fire management includes the following components; prediction of fire occurrence, fire prevention, fire detection, initial attack, fire management, strategic planning of resources, and fuel management. Training, knowledge sharing and planning of the different components of fire management is extremely important (FAO, 2006).

Prediction of fire occurrence requires the identification of the main causes for forest fires, followed by an analysis of factors that influence the frequency of those causes. In Mexico, this has been done through proxy indicators, such as nearness of populations and types of land use (danger assessment). This needs to be combined with characteristics of the fuel, temperatures and moisture content (risk assessment) as well as with an assessment of the value of the resource in order to be able to set priorities in fire prevention and combat activities. In many developed countries, this information is combined with daily weather forecasts to assess fire danger ratings. This has proved to be a useful early warning system (FAO, 2006).

Fire prevention is probably the most cost effective and efficient way to reduce fire damage (FAO, 2006). It requires identification of frequency, size, severity and causes of human induced fires and needs to be followed by awareness campaigns to reduce those causes or projects oriented at training and introduction of alternatives to burning forest and grazing lands. In many regions, for example Mediterranean countries and western states of the United States, watch towers are the main tool for fire detection (Martell, 2007). Patrol flights are used as well but it is difficult to plan them cost effectively (Martell, 2007). Once detected communication of location, size and burning characteristics of the fires among the fire fighters and to the public is very important, especially for the initial attack (FAO, 2006). Whereas in North America it is a problem of deciding how many air tankers to keep on standby for the initial response to fires, in many tropical countries air tankers are not available and initial attack may need to be done by local fire brigades. The quicker the response time, the smaller will be the risk of uncontrolled fires. However, such fire brigades require an extensive program of training of the local teams, as well as sufficient equipment to be able to fight small fires. Initial attacks become more efficient if these are based on previously prepared plans that consider potential impact of fire fighting, as well as the potential risks of damage to natural, human and physical resources.

Fire management requires continuous monitoring of fuel conditions, fire behaviour and climate. With this information and short-term predictions on their changes, fire fighters can decide when and how many people to dispatch to control the fire. Fuel management is one of the more common and discussed approaches to forest fire reduction. Protection of forests has led in many cases to the accumulation of fuel, increasing the risk of forest loss, rather than reducing it. Prescribed burning is a common tool, but this needs to be supervised by experts, in order to avoid the fires to get out of control. Cutting of fire breaks is another measure often taken. These do not only form barriers to fire progress, but may also help accessibility of the forest for fire fighting crews. Technology has proved vital in monitoring and control of forest fires in regions such as North America and Europe. However, in tropical countries, where access to this technology and to the forests is more limited, fire management strategies need to include all stakeholders and all related sectors since most fires originate outside forest lands and involve non-forest stakeholders (van Lierop, 2009).

Risk reduction strategies for damage from hurricanes or cyclones need to consider damage to forest, agricultural crops, communities and infrastructure. Reducing risk of damage to forests can be done through silvicultural practices such as shorter rotation cycles; young trees often are more resistant to wind throw, but if thrown, will result in less biomass lost compared to larger trees. Increasing resilience, for example by maintaining good seed sources and mixed species forests, including species that readily sprout after wind throw is another means of reducing damage.

Box 3.4. Fire risk management in Macedonia, Greece (Nikolov, 2010)

Forest fires are a major problem in the southeast European/Caucasian region: in 2007 for example, 78 people died and the estimated monetary value of damages was well over 250 million US$. Almost 60% of the fires had human causes, related to agricultural practices or negligence. Only 3.3% could be identified as natural causes and of nearly 38% of the fires the causes could not be determined. Under these conditions, an analysis of fire response was done for Macedonia. The study concluded that, in spite of the overall coordination framework that includes different stakeholders with different responsibilities, the response is deficient. The main recommendations address the lack of equipment and knowledge of the local population through awareness campaigns and equipment for early response; the establishment of an early detection system including watchtowers; training of (volunteer) firefighters; national and local annual fire management plans, linking forest health monitoring to forest fire management planning; and establishing a proper command system identifying the different institutions involved and their responsibilities in protection and response activities.

In Toncontín, Honduras, the local community started to improve forest management in 1997, one year before hurricane Mitch struck. The forest is dominated by species resilient to hurricanes through different strategies including rapid and abundant seed regeneration or re-sprouting. Part of the management improvement was the retention of seed trees. Comparative studies one year after Hurricane Mitch indicated that the forest with seed tree retention was recovering its original species composition faster than forests where all commercial trees had been cut without seed tree retention (Acosta *et al.*, 2001).

Improving water regulation

Changes in precipitation patterns probably will affect forests more than changes in temperature at least over the next twenty years. The impacts will depend on the increase in atmospheric CO_2 and the reaction of trees to this increase. The potential water regulation functions of forests therefore, are receiving more and more attention in the forests and climate change discussions. The role of forests in this case is vital not only as a provider of an ecosystem service (in particular in relation to the quality of water for consumption, for irrigation, for industrial use), but also for the survival of the forests themselves. Many myths regarding the function of forests in the water cycle exist (Kaimowitz, 2001; FAO, 2008). Much more research is needed and this research should include studies on the influence of individual trees and forest stands on the local water cycle and the water cycle of watersheds. As a rule of thumb, the original natural vegetation is the best way to regulate the water cycle. Planting trees in grassland swamps, such as one of the water catchment areas of Bogotá, Colombia, may result in rapid depletion of the water resources. On the other hand, leaving trees in dry areas may improve infiltration, soil structure and water holding capacity of the soils. Planting fast growing exotics in such areas may result in depletion of the soils. Dry areas, however, may also be affected by salination and in that case, care should be taken not to increase underground water levels, since this may increase the release of minerals in the upper soil layers (FAO, 2008).

Different plants have different water use efficiencies and these may change when exposed to more sunlight. Oak in Italy appears to be less sensitive to light conditions in its water use efficiency than a local Beech species (D'Alessandro *et al.*, 2004 and 2006). This may imply that beech stands may suffer less from reduced rainfall, since individual trees will react positively to lower stand densities while oak stands, on the other hand, may lose volume. In terms of effect on the regulation of the water cycle, oak may be easier to manage, since thinning of the oak stand will reduce water use more than in beech stands. Couralet *et al.*, (2010) found similar results for species in understory trees in Africa.

Equal treatment of a forest stand in terms of modifications to the microclimate and water availability will have varying effects on the different species. This relationship, however, needs more research. Knowledge of this correlation is useful for adaptation, species selection for local conditions and the estimation of the value of a species and its management system for mitigation. In Argentina and Chile, *Nothofagus pumilio* is suitable for mitigation due to its plasticity, while the regeneration capacity of *N. macrocarpa* was highly affected by the moisture gradient within canopy openings (Peña, 2011). Dietz *et al.*, (2006) in a study in Indonesia, found that tall trees may increase water evapotranspiration and decrease throughfall. This suggests that smaller trees would be better conservers of water. Of course, this is dependent on how well these smaller trees allow the throughfall and stem flow water to infiltrate in the soils, and the water retention capacity of the soils.

Apart from the effects on plant growth of individual species, climate change is likely to affect water availability at a watershed level. There has been an increase in the implementation of projects in upper watersheds with many positive benefits. However, the meta-analysis of Locatelli and Vignola (2009) clearly indicate that this is not always the case. Two strategies can be followed in such cases. They demonstrated the necessity to study the effect of trees on an experimental basis, before promoting large scale regeneration or plantations. In addition, monitoring of water flow at strategic points within the watershed, taking into account current land use practices will allow for changes in the planning of species composition.

In most cases, at the landscape level, control of land use and forest regeneration goes beyond the control of individuals and will need some form of stakeholder collaboration to achieve the desired results. A good case of stakeholder collaboration can be seen in the Dominican Republic, where farmers with land suitable for irrigation allowed owners of land on the ridges to occupy part of their land in return for reforestation on the ridges. It is estimated that for each hectare of irrigated land, thirty hectares are being regenerated, contributing to the availability of water for irrigation (Carrera, 2010).

The Clean Development Mechanism and other carbon initiatives

As early as 1995 the European Union set up the European Trading System (EU ETS), which puts a cap on the country emissions but allows EU countries to trade with other countries whose emissions remain well below the cap. Then in 1997, the Kyoto Protocol (KP) was adopted, although it did not enter into force until 2005. As of September 2011, 191 states have signed and ratified the protocol. Under the KP, 37 countries (Annex I countries) committed themselves to reducing their emissions to a level below that of 1990 and all member countries gave general commitments. They also agreed that countries that have not been able to meet their quota may compensate part of that by either setting up 'joint implementation' projects with other Annex 1 countries, or invest in Clean Development Mechanism (CDM) projects in developing countries (Non-Annex 1 countries). Of the latter, afforestation and reforestation are the only forms of forestry projects eligible. None of the tree or forest carbon offset projects however, are formally recognized within the framework of the ETS. Thus, options for forest carbon trade are limited to the voluntary markets and over the counter trade. In addition, funding is available to finance the costs of developing countries to prepare themselves for Reduced Emissions from Deforestation, Forest Degradation, forest conservation and sustainable forest management (REDD+). The delivery of funds to the countries has however, not reached expectations. Only around 1.5% of the CDM projects, for example, are forestry projects, while at the same time, prices on the voluntary markets fluctuate with expectations of future demand but are nevertheless very low.

CDM projects

Most carbon initiatives are either related to the CDM scheme or set up in a similar manner. These projects, with a few exceptions, are oriented toward sequestration of carbon. Trees are planted and a commitment is made to maintain the area under tree plantations for a minimum period of time, commonly 30 years. Although within forestry circles this is thought to be a reasonable time period, it should be noted that if after thirty years the trees are cut and not replanted, in the long term no carbon has been sequestered, other than that used in long term products (permanence). In addition, the capacity of most tree species to sequester is relatively low. Official IPCC figures, range from around 1 tC/ha/yr to about 10 tC/ha/yr. Within the scheme, requirements for carbon accounting are very strict, raising the costs of entry and thus limiting the participation of small holders in the scheme. In voluntary markets, carbon accounting standards may vary according to the expectations of the buyer. However, buyers are increasingly requesting the strict carbon accounting methods approved by CDM, sometimes accompanied by standards that measure the social and economic impacts of these initiatives (e.g. the Climate, Community and Biodiversity Alliance standards).

REDD+

REDD+ is an international mechanism aimed at avoiding deforestation and forest degradation, promoting sustainable forest management and conservation or enhancement of the forest (carbon stock). The innovative part of REDD+ is the broad international attention and the funding potentially available for the resulting strategies, the focus on carbon rather than on wood and NWFPs, and the recognition that the solution lies in an inter-sectoral approach rather than only within the forest sector. Because of the expectations REDD+ has raised, there are many actors involved, some of them seeing REDD+ as a means to strengthen their own agenda, developed over years or even decades. Foresters see REDD+ as a means to bring forestry for timber management back on the foreground while conservationists focus on opportunities for protected areas. Many NGOs hope to be able to strengthen community forestry, while some indigenous people's organizations view the negotiations on REDD+ as a chance to finally receive formal recognition of their traditional rights. Consultants and investment agencies consider it as an opportunity to sell their services, and some of these may actually exaggerate the potential benefits in order to convince actors to participate. Fortunately, these agendas, in many cases, are complementary and a number of very interesting experiences exist, although not necessarily fitting into the framework of the international negotiations (which are oriented towards national implementation rather than project implementation) or national policies. A good example is the case of Bolivia, where the Noel Kempff project made promising advances in implementation but the lack of support of the national government has prevented further progress (TNC, 2010).

Many of the activities proposed under the REDD+ mechanism are not new but may be differently focused. The aim is to reduce emissions rather than produce specific products or conserve biodiversity. In addition, the approach towards implementation is different with more attention being paid towards processes, such as meaningful participation, free, prior and informed consent (FPIC), conflict resolution mechanisms and monitoring and verification. These are all related to decision-making and stakeholder consultation processes. Examples of projects include SFM initiatives, protected areas systems that have contributed to stall the advances of the agricultural frontier, restoration of degraded forests and reduction of fragmentation. These projects have all been successful in showing the contribution of these activities to avoided deforestation and forest degradation. In addition, successful projects have clarified land, forest and carbon rights, recognizing legitimate claims of the different stakeholders, establishing acceptable cost and benefits sharing mechanisms and implementing activities to avoid negative social and environmental impacts.

Very few of the projects have been designed to fit into national REDD+ strategies. However, lessons can be learned from the existing project experiences for implementation of the future strategies. Forest managers will most likely have to deal less with eliminating the underlying causes of deforestation and degradation, since many of those relate to policies, markets, culture and demographic factors such as population growth and migration. Within a national strategy, it is also less likely that they will have to deal with leakage since this is better dealt with at a broader scale (e.g. directed settlement areas, off-farm employment opportunities, legislation that prohibits land use change from forest to agricultural lands). Monitoring, respect for other people's rights, FPIC and activities to avoid negative social and environmental impacts will need to be designed to be effective locally and at the same time fit into the national REDD+ policy framework. The major tasks for the forest manager within a national REDD+ framework will be management and monitoring of the carbon stock. Managers will be motivated to do so if they perceive benefits from it, usually in the form of extra income and increased access to technical assistance and technology.

Box 3.5. Basic technical requirements pilot carbon initiatives

Currently, REDD+ oriented mitigation projects need to provide information on their baseline stock of carbon; propose future scenarios of carbon flows; show additionality and permanence; and reduce leakage.

Permanence: when the risk of losing the carbon stock through un-expected event is very small. In many REDD+ countries, permanence is achieved through the integration of local people in conservation and monitoring as well as through patrolling and fire, pest and disease management practices. Particularly in hurricane prone countries, permanence is a difficult thing to achieve.

Additionality: when projects would not have occurred without the assistance (technical or financial) of the buyer of credits. Previous difficulties in implementation may have been due to lack of financial return; lack of investment money; lack of technical knowhow or assistance; etc

Leakage: is when deforestation or forest degrading activities in the forest to be managed for mitigation are moved to forests not subject to carbon management as a result of the proposed mitigation activities.

Management and monitoring of the carbon stock in theory should involve all five carbon pools; above ground biomass, dead wood, litter, underground biomass and carbon in the soil. Currently, for REDD+, the above ground biomass is the main pool being discussed, although for projects, the carbon accounting requirements may differ according to the standards used. The verified carbon standard (VCS), for example, considers different methodologies for different REDD+ type of activities. For reducing emissions from mosaic deforestation and degradation (with forest patches <1000 ha surrounded by agricultural fields), VCS include above ground tree-biomass, below ground biomass, dead wood and carbon in products in the carbon accounting. The actual accounting methods usually have to follow the IPCC 2006 guidelines[1].

As can be seen in the Table 1, the other carbon pools may change, but the direction of their change is less well known and depends on local conditions and future land uses. If the changes are expected to be positive, it is accepted practice to exclude the carbon pool, since this would lead to conservative estimates of carbon benefits. Soil carbon pools become more important in boreal and temperate forest areas and in non-forest land uses. In those cases, carbon stock in the soils is usually greater than in the above ground vegetation, and can be highly influenced by land use practices, water run-off and erosion.

In project accounting, several pools are usually considered for the calculation of the baseline. Most of the current carbon initiatives concentrate on monitoring of the above ground biomass as a proxy for carbon content in above and below-ground biomass (TNC, 2010) to provide inputs for accounting of the changes in carbon during the project life. Generally, such monitoring is done through a combination of satellite images and on the ground measurements. In some projects, communities are heavily involved in monitoring their own carbon stocks, thus promoting their appropriation of carbon management (Skutsch *et al.*, 2009). For carbon management, the most interesting conservation sites would be those under highest pressure of conversion. In practice, however, REDD+ pilot initiatives are in areas under little pressure since this usually reduces the initial investments in terms of financial and human resources.

[1] www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html

Table 1. Selecting the carbon pools to be measured following the VCS approved methodology for REDD+ in mosaic landscapes, from www.v-c-s.org/sites/v-c-s.org/files/VM0006

Carbon Pool	Included/Excluded	Justification/Explanation of choice
Above-ground tree biomass	Included	Major carbon pool affected by project activities
Above-ground non-tree biomass	Excluded	Change expected to be positive or insignificant under applicability criteria and therefore can be excluded
Below-ground biomass	Included	Major carbon pool affected by project activities
Dead wood	Included	Major carbon pool affected by project activities
Litter	Excluded	Expected to decrease under the baseline scenario under the applicability criteria
Soil organic carbon	Excluded	Change expected to be positive or insignificant under applicability criteria and therefore can be excluded
Wood products	Included	Major carbon pool affected by project activities

While REDD+ is mainly oriented towards natural forests in developing countries, it is likely that great mitigation benefits may be achieved from agroforestry schemes and soil and forest conservation schemes. However, these benefits will not be the same everywhere. The costs to quantify mitigation levels are too high for forest dependent people and the rural poor to actually be able to capture financial benefit. The payment for environmental services (PES) schemes of Costa Rica and Mexico are good examples of this problem. In Mexico, most *ejidos* need professional advisors to be able to access national PES for water, biodiversity and carbon. Studies of all carbon pools, as required by several market mechanisms, are lengthy, very technical and costly. Even if communities have the money to contract technical assistance, there are not sufficient advisors with the adequate experience to help all communities. In Costa Rica proof of specific environmental services being delivered is not yet required. It is sufficient to show that forest is being maintained. Even then, at least half of the areas receiving PES would have been conserved anyway, while many forest owners prefer to conserve without having to go through the administrative procedures to obtain a relatively small amount of money. This is particularly cumbersome where property rights have not been clearly established. In both countries, NGOs are active in bringing together producers or communities to share costs and in linking these groups to organizations that are interested in buying carbon credits as a component of their social and environmental responsibility policies.

Dealing with market influences on adaptation and mitigation practices in forest management

In many places, forests have disappeared due to conversion to lands for the cultivation of high value crops. In other places, fall in prices of crops or beef have led to abandoned agricultural lands, on which forests regenerate. Increased prices of agricultural crops lead to increased production and increased need for packaging material, which in turn stimulated the establishment of plantations of fast growing tree species. An increase in the value of forest products and services may make it more attractive for forest owners and users to manage the forest than to convert them into marginally producing agricultural or livestock lands. An increased demand for international enterprises to behave in an environmentally responsible manner makes them incorporate forests and trees into their agricultural production plans. All these examples show that markets, whether for agricultural products, forest products or ecosystem services, have a complex and close relation to the way forests are used or conserved and thus can influence the mitigation and adaptive capacities of these forests. With the recent discussions on climate change, three types of relations between markets and forests have become crucial; markets for forest carbon, markets that require social and environmental responsibility of a wide range of companies and markets that influence the relative value of forest use in relation to other land uses.

Box 3.6. Mitigation as part of community forest management in southern states in Mexico

CONAFOR for years has based its assistance to forest communities and ejidos on territorial planning exercises. Several communities in Oaxaca have developed this into local base lines, identifying specific carbon rich areas as potential carbon initiatives. Facilitated by the NGO Pronatura, they have been able to reach an agreement with a carbon buyer that was prepared to buy carbon as part of its social and environmental responsibility program. The buyer paid not just for the carbon, but also for its contribution to local development. This experience will now be improved upon, estimating the carbon in all land uses within a territory and strengthening the communities' capacities to monitor changes in the carbon stock on their farms.

Social-environmental responsibility

In Mexico, the Oaxaca Community Association for Environmental Services (SAO AC) was able to sell carbon credits from sinks at a price of approximately US$ 9/tCO_{2eq} to local companies (www.sao.org.mx). These companies invest as part of their social and environmental responsibility programs.

Markets for forest carbon

Since the KP has been in force, several carbon emissions trading schemes have been established. By far the biggest is the EU ETS (Figure 1), which currently trades more than 80% of all carbon credits (World Bank, 2011) with prices significantly higher than in the voluntary carbon markets. Within the scheme, large GHG emitters have been assigned a maximum amount of GHG that they may emit during an established period of time. Those that emit less than this 'cap' can trade the difference with those that emit more, earn emission reduction units through the Joint Implementation program of the KP flexibility mechanism, or buy Certified Emission Reductions (CERs) through the CDM, also part of the Kyoto flexibility mechanisms. The EU ETS does not recognize sinks, effectively eliminating forest carbon credits from the scheme.

Forest carbon credits can be traded in the voluntary carbon market and its proportion in that market has increased considerably after REDD+ was recognized by the UNFCCC as a legitimate form of emission reduction. Overall, however, the value of carbon traded in the voluntary market has declined (Figure 1), possibly because the expected international agreements did not get through, nor did climate change legislation in the United States.

The World Bank (2011) indicates that future demand and supply of carbon are expected to be in balance and it is not very attractive to set up new carbon initiatives, unless GHG emission reduction commitments in developed countries are strengthened. It is, however, difficult to predict the demand, since it depends also on other (macro) economic factors, such as fossil fuel prices, type of economic development and growth.

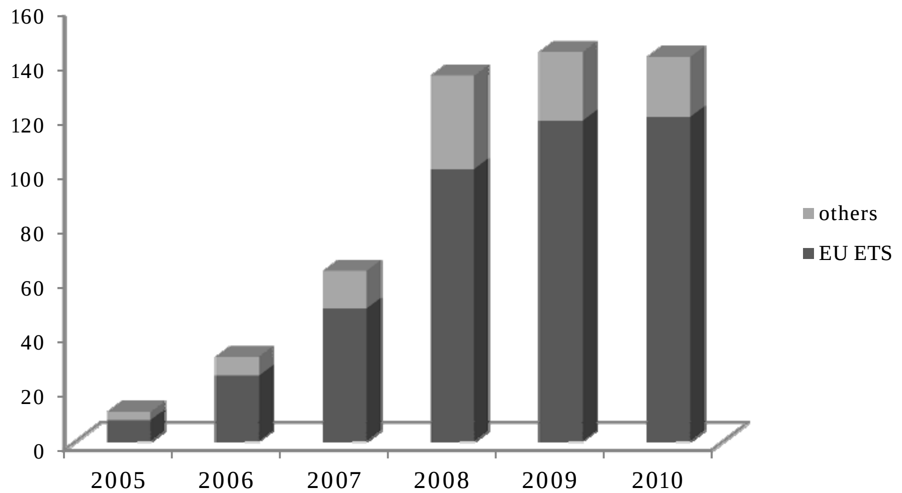

Figure 1. The value of the carbon market from 2005 to 2010 (World Bank, 2011)

Commodity markets have had great influence over the rate of deforestation. It is therefore interesting to see how the private sector is trying to convert the carbon market into another commodity market, with all its advantages and disadvantages. The recent price drops are an indication of the risks involved, both for the owners of carbon rights and for society that counts on the transfer of such rights to mitigate climate. If prices rise and drop rapidly the market will become attractive for speculators, while forest owners may be even more willing to cut their forest if prices drop and they are no longer able to pay for the extra measures they have to take to demonstrate their emissions.

As mentioned in the previous section on REDD+, there is another way of trading carbon, through direct transactions between buyers and suppliers. Some examples exist where communities or community associations in developing countries entered into agreements with companies in developed countries. Such companies are often prepared to pay more than market prices for carbon credits because they also look for additional benefits, usually contributing to their social and environmental responsibility.

Social responsibility requirements

With the focus on conservation and management of the carbon stock, other types of markets are being reconsidered as well. These are markets that promote sustainable forest management and also favour climate mitigation and adaptation. Forest certification, for example, requires a number of the same forest management and conservation requirements as does REDD+, e.g. no deforestation, limited degradation by reduced impact logging practices and fire and pest management. Several forest certification schemes exist, but globally the two best recognized schemes are the Program for Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC). The former endorses national forest management standards, includes the verification of origin of the timber products through a chain of custody certification and already covers more than 200 million hectares of forests, but does not have as good a standing in the market place as FSC. FSC only endorses national indicators that are linked to an international standard and that have been agreed upon through a national process during which there has been equitable participation of social, economic and environmental stakeholder groups. These two certification schemes differ essentially in strictness of social and environmental requirements, appeal procedures and stakeholder participation. FSC is stricter and has more elaborate participatory processes than PEFC while PEFC has greater independence between standard setting and certification bodies. Both schemes are adjusting and are beginning to resemble each other.

Forest certification in general, however, only applies to specific forest management units and therefore has a limited effect on overall deforestation or reforestation rates. These positive effects will depend very much on the scale and intensity of the operations (Putz *et al.*, 2008). A greater positive effect may be perceived on forest degradation. Since certification requires the application of reduced impact logging techniques, it has the potential to reduce damage due to felling and extraction to about half of that of conventional operations (Keller *et al.*, 2004; Putz *et al.*, 2008). Depending on the scale and intensity of the operations this may imply a considerable reduction in emissions. Increasing processing efficiency of the timber, once it has been logged, has a further potential to lower emissions (Bamaca *et al.*, 2006). FSC certification has the potential to contribute to the reduction of emissions from forest degradation, since it has a performance based system.

Although forest certification was originally set up to increase market benefits - access and price - especially for tropical forest producers, currently only market access has been realized. Price increases have been limited to certain cases or in size. Easier access to credit and technical assistance has been seen as an additional benefit. All of these are factors that help increase the adaptive capacity of the forest manager; better organization, greater or more stable income and better access to supporting services. Forest certification also has the potential to also increase the adaptive capacity of forest dependent people; additional training allows them to diversify their economic activities, new employment opportunities help increase and diversify their income and local organizations involved in forest management are strengthened which enables them react to sudden environmental changes. An example of the latter is the village of Toncontin, in Honduras. This was the first village that was able to distribute emergency supplies after Hurricane Mitch hit in October 1998 because they could quickly identify potential beneficiaries and set up a distribution system based on the existing forest management organization.

Other certification schemes, such as schemes that certify biological agriculture or good agricultural practices, also have had a positive effect on the forest, both in area and in quality, and thus have the potential to contribute to both forest mitigation and forest adaptation activities. In Costa Rica, banana companies have purchased forest areas for protection and restoration to offset part of their emissions in the production process and contribute to biodiversity conservation. Throughout the tropics, selected coffee plantations are increasing tree cover to be able to sell their products as 'shade grown' and more recently efforts are on the way to estimate GHG emissions from coffee production to be able to determine the level of carbon neutrality achieved. Carbon sequestration in trees is often seen as a good option to offset some or most of the unavoidable emissions. Such low emission schemes are very promising considering that they may contribute to carbon sequestration and storage - agroforestry systems with coffee or cacao have been reported to store as much carbon as 20 year old secondary vegetation - as well as to strengthening the adaptation capacity of the local agro-ecosystems and their inhabitants, contribute to biodiversity, water regulation and disease and pest control if the shade is well managed. These schemes may also contribute to reducing the level of risk producers face when diversifying their production and securing more stable markets for their cash crops. They may be particularly useful in the context of landscape management, where they offer the opportunity to strengthen management of the ecosystem services throughout the landscape, including in agricultural fields.

Another social responsibility scheme oriented at sharing costs and benefits of ecosystem service management, is the concept of PES. Such schemes may not necessarily be oriented towards carbon sequestration and storage but nearly all existing PES schemes promote the maintenance or enhancement of forest and tree cover. They may or may not require the measurement of the services provided. Some assume that if forest cover is maintained or expanded, or its use limited to carefully management operations (timber, NWFP, conservation, tourism), the desired services are provided. Such is the case of the Costa Rican PES scheme, which pays a flat rate per hectare per year for a mix of carbon sequestration and storage, water regulation, biodiversity maintenance and scenic beauty for each hectare of forest. In Mexico, the first three services are being paid for through separate PES schemes, although all three schemes may have similar results in terms of carbon sequestration and storage, water regulation and biodiversity maintenance. In particular where water resources and biodiversity are at risk due to climate change, the contribution of PES to adaptation may become important. In general, such schemes also offer additional income to producers and forest owners, but in each case the benefits should be evaluated against the costs of meeting entry and monitoring requirements.

Managing uncertainty and risk

The consideration of risk has always been an important part of forest management activities. With climate change, uncertainty is increasing as are the risks of long term investments in forestry. Below are two examples of how the incorporation of uncertainty and risk into management decisions and improved monitoring for early warnings of changing conditions.

The Birris micro watershed

The Birris micro-watershed is located in Costa Rica. Its main landuses are cattle farming (milk and meat) and horticultural activities, while the micro-watershed provides a small hydro-electric power plant with water, later flowing into the Reventazón river with a larger hydro-electric power plant. The micro watershed is likely to suffer from climate change through changes in the onset of the growing season, as well as more severe droughts and high intensity rains. Erosion and sedimentation are likely to be the main direct impact of such changes and are considered by the different stakeholders as being a major issue: for the farmers because they lose fertile soil; by the electric power plants, because it fills up the reservoirs and may damage the machinery. These potential problems were analyzed by different stakeholders and indicators were developed to measure the potential effects of different land use scenarios on components potentially important for climate change adaptation and mitigation capacity of the micro-watershed. Four scenarios were identified by their potential to reduce sedimentation;

- business as usual,
- all critical areas reforested,
- all critical areas under improved soil management and,
- a combination of good soil management throughout the micro-watershed and reforestation in some of the critical areas.

Scientists estimated the values of the indicators for each of the four scenarios and once presented with the result of these studies, participants were requested to agree on one of the four land use options. They chose for an intermediate land use option that requires low initial investments while still reducing the risk that climate change may cause much erosion, and degradation of the agricultural lands and sedimentation of the hydro-electric power dam. Development objectives were thus combined with an assessment of risk of negative impacts of climate change, in this case erosion due to increased rainfall intensity.

Indicators of socio-economic impact of land use

Part of the research undertaken as part of a Mesoamerican Agro-environmental Program (MAP) funded project is focused on identifying indicators that could predict the consequences of land use change, irrespective of the origin of the change. Studies have been carried out on the socio-economic and environmental impacts of different land uses in some Latin-American countries (e.g. Brazil, Costa Rica, Nicaragua) and this information was compared with information on past land use changes in those areas. This analysis should give rise to indicators on the timing and drivers of land use change as well as the potential consequences of these changes. The concept is very similar to the Pressure-State-Response set of indicators used by many countries at the national level within the framework of the UN sustainable development monitoring. The difference between the two lies in the scale and detail, with the MAP project allowing for the downscale of monitoring to landscape level, giving local authorities and stakeholder platforms the tools to predict change and estimate the risk of the negative impacts of those changes. This helps the operationalization of national sustainable development and climate change monitoring systems.

Increase adaptive capacity of ecosystems through forest management

As previously mentioned, forests are important in increasing the adaptive capacity of forest communities, in particular as a safety net in case of emergencies and as a form of diversification of economic activities where NWFPs can be harvested in a sustainable manner. Below, some specific examples of forest management activities that contribute to strengthening local adaptation strategies are discussed.

Box 3.7. Improving the function of forests for flood control through improved agricultural practices

Collaboration between Bangladesh's Forestry Department, Ministry of Land and local communities has enabled the maintenance of the coastal green belt, which protects the communities from major storm surges. Collaboration enabled the sharing of climate change risk information. Although the focus was on conservation and enhancement of the green belt, probably the most successful activity was that of intensifying agricultural practices, establishing mounds that reduced the risk of crop loss through flooding and allowed for more families to live from the available land, reducing the pressure on the forest for conversion.

Management of tree cover to regulate water availability

The importance of forest management for water regulation cannot be overstressed, since water resources are likely to be the resources most affected by future climate change in many parts of the world. Tree cover can be managed to regulate water flow throughout the year, to increase or reduce water flow, or to protect river and coastlines against erosion at times of high water levels. In some cases, such management is promoted through PES schemes, allowing for a more equitable distribution of costs and benefits. In other cases, conservation efforts are oriented at improving the livelihoods of people living in the buffer zones, thus reducing their dependence on the forest for daily subsistence.

Management of hunting

Bushmeat is one of the major NWFPs and in cases of emergency, may become the main source of food for local people. Maintaining viable populations of animal species therefore allows an important emergency supply to be maintained. The main threat to animal populations is hunting beyond sustainable levels. This may occur because of commercial hunting, natural population growth and migration. Over-hunting may lead to unexpected changes in other parts of the forest or its ecological processes. A well-known case of unexpected effects is known from Yellowstone Park in the United States where wolves had been hunted before the park was declared a protected area. This resulted in uncontrolled deer populations within the park, leading to overgrazing and the lack of regeneration for a number of tree species. Hunting of Agouti in Brazil, combined with the elimination of their preferred forest habitat, has led to a decrease in the of regeneration of the protected Brazil nut tree, since the Agouti is the only animal species capable of breaking the hard Brazil nuts and dispersing the seeds. Thus, management of hunting may have positive results on both the fauna and the flora, assisting the maintenance of viable populations and ecological processes. These are necessary for the forests to continue to provide the necessary ecosystem services and provide local people with secondary income as well as a safety net in times of environmental, economic and social stress.

Management of forests and trees within landscapes

Adaptation strategies geared towards communities will in general prioritize food and water security as well as health. In rural landscapes, forests and trees may have an important role in securing food, water and health. Land owners will benefit from mutual collaboration at this scale, identifying priority areas for the protection of water resources, strategies that build a common emergency reserve of seeds and food supply, measures that preserve or improve essential ecosystem services (such as pollination or water quality and soil protection), and measures that will reduce the breeding sites of potential disease vectors (Louman *et al.*, 2010).

Although not necessarily with the explicit intention of adapting to climate change, several territories adhered to the International Model Forest Network that promotes the formulation and implementation of such strategies. In 2010, 58 model forests existed worldwide (IMFN, 2010); 11 of them were implementing specific climate change activities at a landscape scale, while another 9 were working on environmental services. In general, the model forests are seen as good opportunities to implement international agreements on the ground. Their main strength being that they foster local governance and collaboration through voluntary participation in discussion platforms of the local actors. Worth mentioning in this context is the Green Belt Movement, that has shown over the past 30 years that tree planting can contribute to rehabilitation of degraded lands, increased yields of small holder farmers in thousands of communities, while at the same time contributing to CO_2 sequestration (Green Belt Movement).

4. Gaps in enabling conditions required for adequate management responses to climate change

In this section, gaps in the enabling conditions for the forest management responses to climate change are identified and the challenges that these gaps may create analysed. It should be noted that relatively few experiences in forest management responses to climate change have been documented and therefore it is difficult to provide a comprehensive overview of existing capacities and those needed for adaptation and mitigation actions.

Lack of knowledge on climate change impacts on forests

In many tropical countries, information on forest resources (type, quality, extent, values, and changes) is deficient. This information can come from studies on specific topics, (e.g. tree growth of individual species under various conditions), or from local or national monitoring, gathering data with a predetermined frequency on a predetermined set of variables relevant for forest management and conservation. For the more general information, such as forest area, forest quality and species composition, monitoring is the preferred method. In Europe, the United States and some tropical countries, such as Mexico and Chile, such information comes from continuous national forest inventories. In most tropical countries, however, such monitoring mechanisms are limited and sometimes non-existent.

Monitoring

In a revision of national monitoring schemes related to regional SFM standards (such as the Tarapoto process, the Montreal process and the ITTO criteria and indicators for SFM) at a workshop in Chile in April 2011 (Günther *et al.*, in prep.), many similarities were identified between the standards at the criterion level, but countries found it difficult to harmonize monitoring at the indicator level. This was partially due to differences in priorities, but largely also due to differences in capacities to measure the indicators and in the institutional arrangements necessary to measure and share the results between the different state and private entities involved. This is in particular the case for socio-economic data, but also for the quality of forest resources. The quality of monitoring, furthermore, depends on continuity of the measurements, which requires long term funding (often not available in tropical countries), clear and constant definitions of the variables and processes to be measured (such as forest degradation and deforestation and forest quality) as well as compatible measurements over time (also not available for many indicators). The FAO Forest Resource Assessment (FRA) process was recognized as providing a good base to set up and harmonize monitoring tools and mechanisms. However, it was noted that this process suffers from the same obstacles as the existing national and regional processes.

At the project or community scale, monitoring often encounters even greater obstacles, due to the disadvantages of measuring at smaller scales. While it may be possible to simplify monitoring mechanisms, this is only possible if the monitoring results are adequate for the scale, intensity and risk level of the proposed forest operations. Even in certified operations, where monitoring at project scale has developed further than in most other operations, only few well designed and operational monitoring systems exist that actually contribute to improved forest management.

While such monitoring is essential for good forest management at any scale, it needs to be accompanied by monitoring of weather conditions in order to be a useful tool for forest managers to prepare themselves for climate change. In many countries there is no detailed information on weather conditions at the local scale, limiting the ability to relate past and current forest behaviour to weather conditions. In addition, the lack of such data reduces the capability to downscale climate change projections and thus the ability to project climate change impacts at a local scale. It is therefore necessary to increase the number of weather stations throughout much of the tropics (especially the large forest areas), as well as the capacity to analyse the data and incorporate them into impact and climate change models at a local scale.

Research

Research is usually used to solve specific problems or establish links between actions and impacts. It may also be used for a more in-depth understanding of forest processes and the contribution and influence of human activities on forests. Research on climate change impacts and adaptation options have been focused mainly on boreal and temperate forests. Little information exists on impacts of climate change on tropical forests and how tropical forests will react. While potential changes can be studied in field and laboratory trials, it will also be necessary to improve climate change projections at a small scale. Only with reliable local climate change projections will forest managers be able to plan for future changes. Data on the response of species and individual trees to changing environmental conditions is particularly important for plantations, where a limited number of species is planted and thus substitution may not take place when conditions change. For the major timber species, more work is required to identify their levels of resilience to climate change. This information will also be relevant for mitigation, since tree dynamics and its change under changing climatic conditions will influence the capacity to sequester carbon. Research on functional groups may be as relevant specifically for adaptation of forests. There is a lack of case studies highlighting successful cases of forest managers implementing adaptation strategies. Currently, most studies look at tree or animal species. Few have a system approach that includes the environmental, economic as well as the social and technical aspects of forest management.

Much is already known about the relationship between trees and water (FAO, 2008). However, this relation may vary according to geographic, topographic, geological and soil conditions. More studies are required to understand local influences of trees and forests on the hydrological cycle, especially in those areas where climate change is likely to change the amount and the distribution of rainfall over time. Climate induced changes in the water cycle (e.g. increased frequency and severity of droughts and floods), may affect the capacity of local forests and people to adapt to climate change as well as the mitigation potential of forests. Further, there are several myths surrounding the beneficial effects of trees and the negative effects they may have on water availability, soil erosion and other potential ecosystem services. Undoing those myths may be harder than learning from new experiences.

The social and cultural impacts of climate change on forests dependent communities have not been studied widely. Changing forests may change the availability or quality of ecosystem services, resulting in changes in the relationship between people and forests, social relations among people and the degree to which cultural needs are met. This could lead to migration to other areas in search of the lost ecosystem services or other livelihood opportunities. One of the consequences of migration is increased conflicts over resources. There is an urgent need to study these potential conflicts and to recommend options to manage these conflicts.

REDD+ is being widely studied, particularly at the project and national levels. The impact that REDD+ strategies may have on individual households in the medium and long term needs to be further studied to understand the potential contribution that REDD+ may have to local development and biodiversity conservation. While this may not be of direct concern to forest managers, it will, in the long term, be important to avoid social conflicts and the results of such studies may alter the REDD+ mechanisms that are in the process of being designed.

Communication

Monitoring and research will be of little use if the results are not communicated to potential users and the general public at large. IUFRO, among others, have published guidelines for effective communication in the forestry sector (Guldin *et al.*, 2005; Kleinschmit and Krott, 2005) and there are many cases where these guidelines have been successfully applied. In general, however, communication within the sector is weak, resulting in many stakeholders not having access to reliable and updated information. They may miss new opportunities or even act upon incorrect information.

Capacities of forest managers to respond to climate change

Many forest managers are aware of climate change and that it may have positive or negative effects on their forests, but only few have a good understanding of the degree of uncertainty of climate change and impact projections. They are thus susceptible to wrongly interpret those projections unless they receive capacity building on forests and climate change. Most of the existing and proposed actions for mitigation or adaptation to climate change do not require different technical capacities to those already required for SFM. However, it is often not clear to managers that existing best practices may be adequate for the expected or occurring climate induced changes in the natural environment. Even without considering climate change, many forest managers are not up to date with the best practices for SFM. Preparing for climate change, therefore, needs to include capacity building in SFM practices, including integrated fire management, integrated pest and disease management, harvest planning (including road building), silvicultural practices and the implications actions for nutrient and water cycles. The practices to be focused upon during capacity building will depend on the country and target group. In the Mediterranean, for example, training for fire management will be more relevant whereas in tropical American pine forest, pests and diseases may be a more relevant topic, although fire management is also important in these areas. In addition, there is a general need to strengthen the monitoring capacities of forest managers. Awareness raising on adequate monitoring methodologies, tools, and indicators and threshold values that will allow for early detection of changes is also required. This is relevant especially for managers focussing on timber production, forest conservation and protection.

Although the livelihoods of forest dependent people are largely based on NWFPs, there is relatively little awareness of the ecological requirements and management practices of these NWFPs. Capturing that knowledge and sharing it with others will greatly contribute to strengthening adaptive capacity of many communities.

Appropriate technology

Appropriate technology is needed for three major lines of action: monitoring and research, adaptation and mitigation and will vary according to geographic area, type and objective of forest management activity, scale and intensity of operation and existing local human and financial resources. The major problem with the availability of technology is not its existence, but its location and adaptiveness to local conditions. It may be as simple as having instructions for the use and maintenance of equipment only in a foreign language, not readily understood by the intended users. The cost for acquisition and implementation of this technology is another common problem.

Monitoring and research

Monitoring and research of vegetation cover usually requires a range of instruments, from simple measuring tapes to highly sophisticated remote sensors. In addition it requires specific software that allows storage and analysis of the data. While instruments and software exist, they are often not accessible for, or need to be adjusted to the requirements of forest managers. The experience with software for forest inventories shows that tailor-made software has a tendency to get out of date rapidly and after a few years can no longer be used within the new operational systems. It is therefore becoming more common to look for commercial software. The large Canadian based forest products company Tembec, for example, has used a package of commercially available software as basis for their ISO 14001 monitoring system. This, however, requires qualified personnel to combine the software and adjust it to the company's needs. Small and medium scale forest managers, especially in developing countries, will need to collaborate with research and monitoring organizations to be able to make the necessary adjustments in a cost effective way.

Adaptation may require new irrigation technology, as well as breeding technology and seed storage technology. Mitigation, on the other hand, will need technology efficient in energy use.

Gaps in the institutional environment

For the purpose of this document, the institutional environment is considered the framework of formal and informal arrangements that will set the limits for the implementation of climate change preparedness activities. This environment includes the normative framework (legislation and policies), markets and other arrangements to finance forest management and conservation, as well as informal arrangements that direct behaviour of the local actors.

Property rights

Ownership and property rights are a major concern in many regions of the world, particularly for indigenous people in developing countries. There are some cases where rights and tenure are protected by legislation but enforcement is oftentimes lacking. In Costa Rica, for example, land, tree and carbon rights are well-defined, but still a considerable part of the defined rights in the northern zone of Costa Rica are currently under dispute. In other countries, poor people are characterized by not having legal access to land.

Normative framework

While many countries have recently revised or developed forest legislation, the normative framework for forests and climate change needs to go well beyond legislation and policies of the forest sector. Commerce, transport, agriculture and finance are just a few of the other sectors that have a great influence on what happens in forestry. Mechanisms to foster this intersectoral collaboration are often nonexistent in most countries and often climate change is dealt with outside of the forestry sector.

The different actors of the forestry sector are often not well-organized at the local, national or international levels and have little experience in transparent policy setting and implementation. In many cases this has led to a lack of trust, which makes collaboration even more difficult.

Financial arrangements

Investment costs of change are high, while at the same time forest owners or users do not have access to financial mechanisms that help cover those costs. REDD+ talks have created great expectations amongst developing countries however there have been many obstacles thus far for the successful implementation of REDD+ activities. It is thought that the costs for REDD+ implementation may exceed the capacity of developed countries. Further, developing countries do have the absorption capacity for the REDD+ funds. This may leading to uncontrolled spending and may do more harm than good in the long term.

Markets for carbon from trees and forests are still not well established and there are no generally acceptable and workable definitions of permanence, additionality and leakage or measuring and monitoring systems in place. Few effective PES schemes exist, mainly because the institutional structure is not in place or too expensive to operate (e.g. monitoring of services provided).

5. Conclusions

The main objective of this paper was to review how forest management is changing or could change in order to respond effectively to climate change challenges and opportunities. The relationship between climate change and forests was analysed and the major challenges that climate may pose for different forest management objectives were identified.

The potential impacts of climate on forests vary according to geographical region and local topography and land uses, but with only a few exceptions, temperature is expected to increase. In some areas, change may be well above the 2° Celsius considered critical for survival of current ecosystems and will show greater fluctuations than in the past. Changes in precipitation are more difficult to project and are more influenced by local factors. Climate change preparedness will include, therefore, the ability to monitor what changes in climate are actually occurring and what secondary impacts these may have on forests and the management of these forests. This does not mean however, that each forest manager needs to set up his own monitoring system, rather forest managers should be involved in monitoring, through participation in or support to local monitoring platforms, usually involving local universities.

In general, the main challenges posed by climate change for achieving the forest management objectives are:

- improving the down-scaling of climate change and climate change impact models and the incorporation of more local information;
- the potential strengthening effects of poor forest and land management on the impacts of climate change;
- maintaining essential ecosystem services under changing conditions;
- collaborative land management to reduce the negative impacts of the consequences of climate change (e.g. fires and disease outbreaks);
- management of changing water resources;
- adaptation of management practices without introducing new problems;
- management of human migration due to the impacts of climate change elsewhere;
- adaptation of legislation to the demands of a changing world: in particular defining and protecting the rights over valuable products of ecosystem services, such as carbon;
- adaptation of forest management to new market conditions, at the same time ensuring ecological integrity and social benefits;
- management of forests and trees as part of dynamic landscapes, in which forest managers interact with their neighbours in search for synergies and sustainable land management.

The literature review found that many forest managers do not recognize the possible effects that climate change has or may have on forest management, and of those that do, many may have general ideas of how to address actual or expected impacts but do not implement specific activities due to either lack of access to finance or access to knowledge and technical assistance. In spite of this, many forest managers implement strategies that address current threats to forest resources. Since in many cases, climate change impacts will not be new threats, but rather intensification of already existing threats, current measures taken may well address climate change effects (e.g. fire management, pest and disease control and management and many SFM practices). In developing countries in particular, such practices are known but implemented only on a limited scale because of a series of barriers that these countries have not been able to overcome. It is notable that in general, where different stakeholder groups (e.g. state, enterprise and communities) are working together, greater advances were achieved.

In other cases, managers may be aware and have the technical knowledge of how to address the potential climate change impacts, but not the specific knowledge for implementation, simply because it does not yet exist. This is the case, for example, with species or varieties better adapted to the expected new conditions. Only further research will be able to provide the answers. There are cases where practices in one country have been adapted to expected climatic conditions, which are similar to the current conditions of another country. In such cases it will be useful to facilitate information exchange between these countries. Forest managers may be stimulated to respond to climate change through incentive schemes, such as PES or markets that require a certain level of socio-environmental responsibility of the producers and their immediate buyers. However, in many countries the institutional setting is not sufficiently strong to allow for transparent compensation or incentive schemes.

In terms of mitigation**,** there were more examples of the implementation of climate change response measures. The most common are tree planting (private forest owners) and conservation and SFM (NGOs, community based organizations, indigenous communities and forest services). Some of these managers are already considering the potential effects of climate change on their plantations or forests and their potential for mitigation, thus combining measures of mitigation with those of adaptation. Unfortunately, these managers are still very few and most of them lack the knowledge of the opportunities that mitigation may offer.

Most examples of management strategies in commercial forestry are focussed on adapting their management strategies to changing market conditions while community forestry examples are more oriented towards ecosystem conservation and restoration, usually supported by third parties. Government actions in general, have been weak, only partially addressing some of the major challenges and leaving a series of enabling conditions for climate change preparation in the forest sector poorly attended.

This paper concludes that for mitigation, the following barriers need to be overcome:

- definition of rights (land, forest carbon);
- free prior and informed consent mechanisms need to be in place;
- cost and benefit distribution mechanisms need to be developed;
- the opportunity cost approach needs to be oriented to the immediate causes of land use change avoiding speculation and high fluctuation in prices;
- mitigation and adaptation actions should be integrated;
- requirements for monitoring and verification (reliable baseline, additionality, leakage, and permanence data) should be reasonable and for small and intermediate forest managers;
- best practices and lessons learnt from past forest management actions need to be documented and shared;
- awareness raising campaigns on climate change targeted to forest managers need to be developed;
- stakeholder platforms need to be established to ensure transparency and equity in all agreements.

To strengthen adaptation measures, the following enabling conditions need to be strengthened:

- more research and development is required for:
  - monitoring systems;
  - species and varieties with greater flexibility to changing environmental and climate conditions and greater resistance and resilience to fires, insects and diseases;
  - optimum management cycles;
  - impact modelling on national and local scales;
  - motivation for change and related incentive mechanisms.

- improved training on existing SFM practices vital for improved preparedness for climate change;
- communication and awareness raising campaigns developed to:
    - share best practices with all stakeholders and facilitate the exchange of information between countries;
    - incorporate monitoring results into participative decision-making processes;
    - make information accessible and understandable in different forms and to different.
- improvements in the institutional framework for:
    - clarifying rights and ensuring greater equity;
    - ensuring a multisectoral approach (many good adaptation practices are currently discouraged by subsidies or restrictions in other sectors);
    - improved local governance; above all building trust between different stakeholders and identifying common goals and strategies.
    - financial and technical assistance, in particular in relation to carbon markets. This assistance should consider:
        - the scope, size and duration of actions (adaptation actions may need financial support for long term activities, rather than the usual four to five year project lifespans).
        - synergies between adaptation and mitigation.

6. References

Acosta, L., Louman, B. & Galloway, G. 2001. Regeneración de especies arbóreas después del huracán Mitch en bosques manejados de la costa Norte de Honduras. *Revista Forestal Centroamericana* 34: 61-65.

Aguilar-Amuchastegui N., Finegan, B., Louman, B. & Delgado, D. 2000. Patrones de respuesta de Scarabaeinae a las actividades de manejo en bosques naturales tropicales. *Revista Forestal Centroamericana* edición especial abril-junio 2000: 40-45.

Amato, A.W., Bradford, J.B., Fraver, S. & Palik, B.J. 2011. Forest management for mitigation and adaptation to climate change: insights from long-term silvicultural experiments. *Forest Ecology and Management* 262 (5): 803-816.

Angelsen, A., Brown, S., Loisel, C., Peskett, L., Streck, C. & Zarin, D. 2009. Reducing emissions from deforestation and forest degradation (REDD): an options assessment report prepared for the government of Norway. Meridian Institute, Washington, DC.

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.

Bamaca, E., Kanninen, M., Louman, B., Pedroni, L. & Gomez, M.X. 2006. Dinámica del carbono en los residuos forestales producidos durante el aprovechamiento y el aserrío en la Reserva de Biosfera 'Maya', Petén, Guatemala. *Recursos Naturales y Ambiente* 2006, 41, 102-110.

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.

Billings R., Clarke S.R., Espino J.V., Cordón B., Meléndez J., Campos R. & Baeza G. 2004. Bark beetle outbreaks and fire: a devastating combination for Central America's pine forests. *Unasylva* 55, 15-21

Biringer, J., Guariguata, MR., Locatelli, B., Pfund, J., Spanger-Siegfried, E., Suarez, AG., Yeaman, S. & Jarvis, A. 2005. *Biodiversity in a changing climate: a framework for assessing vulnerability and evaluating practical responses*. In: Robledo, C., Kanninen, M., Pedroni, L., (eds) 2005. Tropical Forests and Adaptation to Climate Change: in Search of Synergies, CIFOR, Bogor, Indonesia. Pp 154-183.

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.

Bradshaw, S. D., Dixon, K. W., Hopper, S.D., Lambers, H. & Turner, S.R. 2011. Little evidence for fire-adapted plant traits in Mediterranean climate regions. Trends in Plant Science 16(2): 69-76.

Bray, D.B., Duran, E., Ramos, V.H., Mas, J-F., Velazquez, A., McNab R.B., Barry, D. & Radachowsky, J. 2008. Tropical deforestation, community forests, and protected areas in the Maya forest. *Ecology and Society* 13(2): 56.

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

Brondizio, E. S. & Moran, E. F. 2008. Human dimensions of climate change: the vulnerability of small farmers in the Amazon. Philosophical Transactions of the Royal Society B: *Biological Sciences* 363 (1498): 1803-1809.

Bunnell, F.L., Squires, K.A., & Houde, I. 2004. Evaluating effects of large-scale salvage logging for mountain pine beetle on terrestrial and aquatic vertebrates. Natural Resources

Canada, Canadian Forest Service, Pacific Forestry Centre 506 West Burnside Road, Victoria, BC V8Z 1M5.

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.

Carrera, F. 2010. *ADESJO, una organización comunitaria fuerte y la reforestación como estrategia de desarrollo*. In Sabogal, C. & Casaza, J. (eds.) 2010. Casos ejemplares de manejo forestal sostenible en América Latina y el Caribe. FAO, Rome. Pp 102-108.

Chakraborty, S., Luck, J., Hollaway, G., Freeman, A., Norton, R., Garrett, K.A., Percy, K., Hopkins A., Davis, C. & Karnosky, D.F. 2008. Impacts of global change on diseases of agricultural crops and forest trees. CAB Reviews: *Perspectives in Agriculture, Veterinary Science, Nutrition and Natural Resources* 3 (54): 1-15.

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.

Clarke, S. 2004. Regional strategy for forest health management in Central America; Belize, Guatemala, El Salvador, Honduras and Nicaragua. International consultancy report. FAO, Rome.

Corbera, E., Estrada, M., May, P., Navarro, G. & Pacheco, P. 2011. Rights to land, forests and carbon in REDD+: insights from Mexico, Brazil and Costa Rica. Forests 2011, 2(1): 301-342.

Couralet, C., Sterck, F.J., Sass-Klaassen, U., Van Acker, J. & Beeckman, H. 2010. Species-specific growth responses to climate variations in understory trees of a Central African rain forest. *Biotropica* 42(4):503-511.

D'Alessandro, C., Saracino, A. & Borghetti, M. 2006. Thinning affects water use efficiency of hardwood saplings naturally recruited in a *Pinus radiata* D. Don plantation. *Forest Ecology and Management* 222 (1-3): 116-122.

D'Alessandro, C., Guerrieri, M.R. & Saracino, A. 2004. Comparing carbon isotope composition of bulk wood and holocellulose from *Quercus cerris, Fraxinus ornus* and *Pinus radiata* tree rings. Forest 1 (1): 51–57.

Diaz, S., Tilman, D., Fargione, J., Chaopin, F.S., Dirzo, R., Kitzberger, T., Gemmill, B., Zobel, M., Vila, M., Mitchell, C., Wilby, A., Daily, G.C., Galetti, M., Laurance, W.F., Pretty, J., Naylor, R., Power, A. & Harvell, D. 2005. *Biodiversity regulation of ecosystem services*. In: Hassan, R., Scoles, R. & Ash, N. (eds.). Ecosystems and Human Well-Being: Current State and Trends. Millennium Ecosystem Assessment Volume Island Press, Washington, DC.

Didham, R., Ghazoul, J., Stork, N.E. & Davis, A.J. 1996. Insects in fragmented forests: a functional approach. *Trends in Ecology and Evolution* 11 (6): 255-260.

Dietz, J., Hölscher, D., Leuschner, C. & Hendrayanto. 2006. Rainfall partitioning in relation to forest structure in differently managed montane forest stands in Central Sulawesi, Indonesia. *Forest Ecology and Management* 237(1-3):170-178.

Domingues, T.F., Martinelli, L.A. & Ehleringer, J.R. 2006. Ecophysiological traits of plant functional groups in forest and pasture ecosystems from eastern Amazonia, Brazil. *Plant Ecology*, DOI 10.1007/s11258-006-9251-z.

Dukes, J., Pontius, J., Orwig, D., Garnas, J.R., Rodgers, V.L., Brazee, N., Cooke, B., Theoharides, K.A., Stange, E.E., Harrington, R., Ehrenfeld, J., Gurevitch, J., Lerdau, M., Stinson, K., Wick, R. & Ayeres, M. 2009. Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of northeastern North America: What can we predict? *Canadian Journal of Forest Research* 39(2): 231-248.

Erskine, P.D., Lamb, D. & Bristow, M. 2006. Tree species diversity and ecosystem function: Can tropical multi-species plantations generate greater productivity? *Forest Ecology and Management* 233(2-3):205-210.

Faccoli, M. & Stergulc, F. 2008. Damage reduction and performance of mass trapping devices for forest protection against the spruce bark beetle, *Ips typographus* (Coleoptera: Curculionidae: Scolytinae). *Annals of Forest Science* 65(3):309-309.

FAO. 2005. *Best practices for improving law compliance in the forestry sector.* FAO Forestry Paper 145. Rome.

FAO. 2006. *Fire management voluntary guidelines. Principles and strategic actions*. Fire Management Working Paper FM17E. Rome.

FAO. 2008. *Forests and water*. FAO Forestry Paper 155. Rome.

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

FAO. 2009b. *Global review of forest pests and diseases*. FAO Forestry Paper 156. Rome.

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

FAO. 2011. *Guide to implementation of phytosanitary standards in forestry*. FAO Forestry Paper 164. 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.

Forbes, R.D. & Meyer, A.B. 1955. Forestry Handbook. Society of American Foresters, New York.

Geist, H.J. & Lambin, E.F. 2001. What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. *LUCC Report Series* 4.

Gemenne, F. 2011. Climate-induced population displacements in a 4°C+ world. *Phil. Trans. R. Soc. A* 2011 369, 182-195.

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.

González-Cabán, A. *ed*. 2009. *Proceedings of the third international symposium on fire economics, planning and policy: common problems and approaches*. General technical report PSW-GTR-277 (2009), Pacific Southwest Research Station, USDA Forest Service, Riverside, California.

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

Grau, H.R. & Aide, M. 2008. Globalization and land-use transitions in Latin America. *Ecology and Society* 13(2): Art. 16.

Green Belt Movement. www.greenbeltmovement.org/w.php?id=98. (Accessed on 1 October 2011).

Griscom, H.P. & Ashton, M.S. 2011. Restoration of dry tropical forests in Central America: a review of pattern and process. *Forest Ecology and Management* 261(10):1564-1579.

Guldin, R., Parrotta, J. & Hellstrom, E. 2005. Working effectively at the interface of forest science and policy. *IUFRO occasional paper* no 17. IUFRO, Viena, Austria.

Günther, S., Louman, B. & Oyarzún, V. *in prep*. Criterios e indicadores para mejorar la capacidad de monitorear los bosques y promover el manejo forestal sustentable:

intercambio de ideas para los procesos de Montreal y de América Latina. Memoria of a workshop in Valdivia, Chile, April 2011.

Harvey C. A., Zerbock O., Papageorgiou S. & Parra A. 2010. *What is needed to make REDD+ work on the ground? Lessons learned from pilot forest carbon initiatives*. Conservation International, Arlington, Virginia, USA.

Hefeeda, M. & Bagheri, M. 2008. Forest fire modeling and early detection using wireless sensor networks. *Ad Hoc & Sensor Wireless Networks* 7:169-224.

Holdridge, L.A. 1967. Life zone ecology. Tropical Science Center, San José, Costa Rica.

Imbach, P., Molina, L., Locatelli, B. & Corrales, L. 2010. *Vulnerabilidad de los servicios ecosistémicos hidrológicos al cambio climático en Mesoamérica*. *In*: Martinez-Alonso, C., Locatelli, B., Vignola, R., Imbach, P., (eds), 2010. Adaptación al cambio climático y servicios ecosistémicos en América Latina. CATIE, Serie técnica, manual técnico no 99. Turrialba, Costa Rica.

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.

International Model Forest Network (IMFN). 2010. www.imfn.net (consulted 29 September 2011).

Isaev, A. & Krivosheina, N. 1976. The principles and methods of the integrated protection of Siberian forests from destructive insects. *Ecological Bulletins* (21):121-124.

Jain, S.K., Sunil, K. & Alok, C. 2011. Jatropha biodiesel: key to attainment of sustainable rural bioenergy regime in India. *Archives of Applied Science Research* 3(1):425-435.

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

Jimenez, M., Finegan, B., Herrera, B., Imbach, P. & Delgado, D. 2009. *Resiliencia 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.

Kanninen, M., Murdiyarso, D., Seymour, F., Angelsen, A., Wunder, S. & German, L. 2007. Do trees grow on money? *Forest Perspectives* 4. CIFOR, Bogor, Indonesia.

Keller, M.K., Asner, G.P., Silva, N. & Palace, M. 2004. *Sustainability of selective logging of upland forests in the Brazilian Amazon: carbon budgets and remote sensing as tools for evaluation of logging effects. In* Working Forests in the Neotropics. Zarin, D.J., Alavalapati, J.R.R., Putz, F.E., Schmink, M. *eds*. Columbia University Press: New York, NY, USA.

Kelty, M.J. 2006. The role of species mixtures in plantation forestry. *Forest Ecology and Management* 233(2-3):195-204.

Kleinschmit, D. & Krott, M. *eds*. 2005. *Public Relations for Forest Science*. IUFRO Task Force for Public Relations and IUFRO's Special Programme for Developing Countries (IUFRO-SPDC).

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

Laneve, G., Castronuovo, M.M. & Cadau, E.G. 2006. Continuous monitoring of forest fires in the Mediterranean area using MSG. *IEEE Transactions on Geoscience and Remote Sensing* 44(10):2761-2768

Lawrence, A., Paudel, K., Barnes, R. & Malla, Y. 2006. Adaptive value of participatory biodiversity monitoring in community forestry, Nepal. *Environmental Conservation* 33: 325-334.

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. & Vignola, R. 2009. Managing watershed services of tropical forests and plantations:can meta-analyses help? *Forest Ecology and Management* 258 (9): 1864-1870.

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.

Louman, B. *in print*. Forest management in Costa Rica. *In*: Mohren, F. & van Kanten, R. CELOS Management System, CELOS, Suriname.

Louman, B., Fischlin, A., Glueck, P., Innes, J., Lucier, A., Parrotta, J., Santoso, H., Thompson, I. & Wreford, A. 2009. *Forest ecosystem services: a cornerstone for human well-being*. *In*: Seppala, R., Buck, A. & Katila, P. 2009. Adaptation of forests and people to climate change. IUFRO World Series 22.

Louman, B., DeClerck, F., Ellatifi, M., Finegan, B. & Thompson, I. 2010. *Forest biodiversity and ecosystem services: drivers of change, responses and challenges*. *In*: Mery, G., Katila, P., Galloway, G., Alfaro, R., Kanninen, M., Lobovikov, M., Varjo, J. *eds*. 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.

Magrath, J. & Sukali, E. 2009. The winds of change: climate change, poverty and the environment in Malawi. Oxfam Research Reports, Oxfam International.

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.

Martell, D. 2007. Forest fire management. In: Weintraub, A., Romero, C., Bjørndal, T. & Epstein, R. *eds*. Handbook of Operations Research in Natural Resources. International Series in Operations Research & Management Science 99(3):489-509.

Martin, P. 2010. Climate change, agricultural development, and migration. The German Marshall Fund of the United States, Washington, DC.

Mascaro, J., Perfecto, I., Barros, O., Boucher, D.H., De La Cerda, I.G., Ruiz, J., & Vandermeer, J. 2005. Aboveground biomass accumulation in a tropical wet forest in Nicaragua following a catastrophic hurricane disturbance. *Biotropica* 37(4):600-608.

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.

Mazour, M., Boughalem, M. & Benmansour, M. 2010. Improvement of the Mediterranean cork-oak forest of Zerdeb using grazing flocks. *IOBC/wprs Bulletin* 57:175-178.

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.

Mendoza, F., Chévez, M. & González, B. 2001. Sensibilidad de las zonas de vida de Holdridge en Nicaragua en función del cambio climático. *Revista forestal Centroamericana* 33: 17-22

Millar, C.I., Stephenson, N.L. & Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications* 17(8):2145-2151.

Millenium Ecosystem Assessment (MEA). 2005. Ecosystem and human well-being : synthesis. Island Press, Washington D.C.

MINAE. 2002. El éxito forestal de Costa Rica en cinco casos. Ministerio del Ambiente y Energia, San José, Costa Rica.

Mori, A.S. 2011. Ecosystem management based on natural disturbances: hierarchical context and non-equilibrium paradigm. *Journal of Applied Ecology* 48(2):280-292

Morse, W.C., Schedlbauer, J.L., Sesnie, S.E., Finegan, B., Harvey, C.A., Hollenhorst, S.J., Kavanagh, K.L., Stoian, D., & Wulfhorst, J.D. 2009. Consequences of environmental service payments for forest retention and recruitment in a Costa Rican biological corridor. *Ecology and Society* 14(1): 23.

Nawir, A.A., Kassa, H., Sandewall, M., Dore, D., Campbell, B., Ohlsson, B. & Bekele, M. 2007. Stimulating smallholder tree planting – lessons from Africa and Asia. *Unasylva* 228 (58): 53-58.

Nepstad, P. 2008. The amazon's vicious cycles. Fire and drought in the greenhouse. WWF International, Gland, Switzerland.

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.

Nichols, J.D., Bristow, M. & Vanclay, J.K. 2006. Mixed-species plantations: prospects and challenges. *Forest Ecology and Management* 233(2-3):383-390.

Nikolov, N. 2010. *Management practices to reduce elevated forest fire risk due to climate change. Case study of Central Europe and Mediterranean region*. Presentation during the Forest Fire Workshop, held the 15th of November 2010 in Yerevan, Armenia. UNDP/GEF/Ministry of nature protection of the Republic of Armenia project 00051202.

Noss, R.F. 2001. Beyond Kyoto: forest management in a time of rapid climate change. *Conservation Biology* 15(3):578-590.

Ollinger, S., C. Goodale, Hayhoe, K. & Jenkins, J.P. 2008. Potential effects of climate change and rising CO_2 on ecosystem processes in northeastern U.S. forests. *Mitigation and Adaptation Strategies for Global Change* 13 (5): 467-485.

Ostrom, E. & Nagendra, H. 2006. Insights on linking forests, trees, and people from the air, on the ground, and in the laboratory. *Proceedings of the National Academy of Sciences* 103(51):19224-19231.

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 socio-economic impacts and vulnerabilities*. *In*: Seppala, R., Buck, A. & Katila, P. 2009. Adaptation of forests and people to climate change. IUFRO World Series 22.

Peña, K. 2011. *Gestión forestal sostenible de los bosques Andino Patagónicos de Nothofagus: estrategias de adaptación y mitigación para el manejo y la conservación debido al cambio climático*. Informe preliminar proyecto MIA.

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.

Pfaff, A., Robalino, J.A. & Sanchez-Azofeifa, G.A. 2008. Payments for environmental services: empirical analysis for Costa Rica. *Working papers series SAN08-05*, Terry Sanford Institute of Public Policy, Duke University, Durham, North Carolina, USA.

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.

Piotto, D. 2008. A meta-analysis comparing tree growth in monocultures and mixed plantations. **Forest Ecology and Management** 255(3-4):781-786.

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.

Pressey, R., Ferrier, S., Hager, T., Woods, C., Tully, S. & Weinman, K. 1996. How well protected are the forests of north-eastern New South Wales? Analyses of forest environments in relation to formal protection measures, land tenure, and vulnerability to clearing. *Forest Ecology and Management* 85(1-3):311-333

Putz, F.E., Zuidema, P.A., Pinard, M.A., Boot, R.S.A., Sayer, J.A., Sheil, D., Sist, P., Elias & Vanclay, J.K. 2008. Improved tropical forest management for carbon retention. *PLoS Biology* 2008 6(7):e166.

REDD-Net Bulletin Asia-Pacific. 2010. *The role of trust in REDD+*. RECOFTC, Bangkok, Thailand.

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

Rojas, M.R., Locatelli, B. & Billings, R. 2010. Cambio climático y eventos epidémicos del gorgojo descortezador del pino Dendroctonus frontalis en Honduras. *Forest Systems* 19(1):70-76.

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 CO_2 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.

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.

Steele, B.B., Bayn Jr., R.L. & Val Grant, C. 1984. Environmental monitoring using populations of birds and small mammals: Analyses of sampling effort. *Biological Conservation* 30(2):157-172.

Stern, N. 2006. *The Stern Review: the economics of climate change*. Cambridge University Press, the Edinburgh Building, Cambridge.

Stoian, D. 2004. *Cosechando lo que cae: la economía de la castaña (Bertholletia excelsa H.B.K.) en la Amazonía boliviana. In*: Alexiades, M.N. & Shanley, P. eds. 2004. Productos forestales, medios de subsistencia y conservación. Estudios de caso sobre sistemas de manejo de productos forestales no maderables. Vol. 3 América Latina.

Sunderlin, W.D., Hatcher, J. & Liddle, M. 2008. *From exclusion to ownership? Challenges and opportunities in advancing forest tenure reform*. Rights and Resources Initiative, Washington DC.

Suyanto, S., Applegate, G. & Tacconi, L. 2002. *Community-based fire management, land tenure and conflict: insights from Sumatra, Indonesia*. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand.

Suyanto, S., Ksususiyah, N. & Permana, R.P. 2002b. The role of land tenure in improving sustainable land mangement and the environment in a forest zone in Lampung Sumatra. Project report. ICRAF, Nairobi, Kenya.

Syphard, A.D., Keeley, J.E. & Brennan, T.J. 2011. Comparing the role of fuel breaks across southern California national forests. *Forest Ecology and Management* 261(11):2038-2048.

The Nature Conservancy (TNC). 2010. *Reducing emissions from deforestation and degradation (REDD): a case book of on the ground experience*. The Nature Conservancy, Conservation International and Wildlife Conservation Society, Arlington, Virginia.

Tilman, D., Knops, J., Wedin, D., Reich, P., Ritchie, M. & Siemann, E. 1997. The influence of functional diversity and composition on ecosystem processes. *Science* 277: 1300-1302.

Turchin, P. & Odendaal, F.J. 1996. Measuring the Effective Sampling Area of a Pheromone Trap for Monitoring Population Density of Southern Pine Beetle (Coleoptera: Scolytidae). *Environmental Entomology* 25:582-588.

Van Lierop, P. 2009. *FAO and partners in fire management: a participatory and integrated approach*. *In*: González-Cabán, A. *ed*. Proceedings of the 3rd International Symposium on fire economics, planning and policy: common problems and approaches. General technical report PSW-GTR-277, Pacific Southwest research Station, USDA Forest Service, Riverside, California.

Vandermeer, J., Boucher, D.H., Granzow de la Cerda, I. & Perfecto, I. 2001. Growth and development of the thinning canopy in a post-hurricane tropical rain forest in Nicaragua. *Forest Ecology and Management* 148(1-3):221-242.

Vandermeer, J., Cerda, I., Boucher, D., Perfecto, I. & Ruiz, J. 2000. Hurricane disturbance and tropical tree species diversity. *Science* 290(5492):788-791.

Walters, B.B., Sabogal, C., Snook, L.K. & de Almeida, E. 2005. Constraints and opportunities for better silvicultural practices in tropical forestry: an interdisciplinary approach. *Forest Ecology and Management* 209: 3-18.

Waring, K., Reboletti, D., Mork, L.A., Huang, C-H., Hofstetter, R.W., Garcia, A.M., Fulé, P.Z. & Davis, T.S. 2009. Modeling the impacts of two bark beetle species under a warming climate in the Southwestern USA. *Ecological and Economic Consequences. Environmental Management* 44 (4): 824-835.

Wermelinger, B. 2004. Ecology and management of the spruce bark beetle *Ips typographus*: a review of recent research. *Forest Ecology and Management* 202 (1-3):67-82.

White, M. & Martin, A. 2002. *Who owns the world's forests*? Forest Trends. Washington DC.

Williamson, M. 2010. Análisis multitemporal para la detección de cambios en el uso del suelo en tres municipios afectados por el huracán Juana. *Wani* 58(0):52-57.

World Bank. 2011. State and trends of the carbon market 2011. The World Bank, Washington DC.

Wünscher, T. 2008. *Spatial targeting of payments for environmental services in Costa Rica: a site selection tool for increasing conservation benefits*. PhD Dissertation, Rheinischen Friedrich Wilhelm Universität, Bonn, Germany.

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