Executive Summary and Key Messages

1 Forest Ecosystem Services: A Cornerstone for Human Well-Being

Greenhouse gas emissions are the main anthropogenic cause of current climate change. The magnitude of future change will be affected by the extent to which these emissions are reduced. Regardless of climate change mitigation activities implemented today or in the near future, however, historical emissions and inertia in the climate system mean that further climate changes are inevitable. Some effects of climate change are already noticeable and there is a need and opportunity to be better prepared for future change. Individuals, societies and institutions should be aware of the impacts that climate change is likely to have and should have strategies in place to adapt to them.

Forest, and the goods and services they provide, are essential for human well-being. An assessment of the likely impacts of climate change on forests and forest-dependent people, therefore, is important for effective climate change adaptation. Such an assessment can also assist the development of options for avoiding the harmful effects of climate change and to take advantage of the opportunities provided by it.

This report assesses:

- the interrelations among forest ecosystems, the services they provide, and climate change
- the past and future impacts of climate change on forest ecosystems and the people that depend on these ecosystems
- management and policy options for adaptation.

Adaptation is defined as:
'Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'.

It can be anticipatory or reactive, autonomous or planned. In some cases, expected changes in the climate will merely require anticipatory or planned adaptation based on the modest adjustment of current practices. In many cases, however, novel innovative strategies will be needed.

The vulnerability to climate change of forests and the human systems depending on them varies greatly by region and forest type. According to the Intergovernmental Panel on Climate Change, vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed (its *exposure*), the *sensitivity* of a system to change, and its *adaptive capacity* (i.e. resilience). The vulnerability of human systems is determined by factors such as the social and economic situation of households and communities, their geographical locations and cultural backgrounds, and their access to resources and political and economic power. All such factors must be taken into account in determining the adaptation options, or combinations of adaptation options, that are most practical and desirable.

Forest ecosystems provide a wide range of supporting, provisioning, regulating and cultural services ('ecosystem services'). Together with existing socioeconomic processes (e.g. deforestation, forest fragmentation, other forms of habitat loss, population growth, income growth and urbanisation), however, climate change could lead to significant changes in the delivery of such services.

Sustainable forest management is a system of forestry practices that aims to maintain and enhance the economic, social and environmental values of all types of forest. In the context of climate change, the principles of sustainable forest management can be applied to reduce the exposure and sensitivity of a forest and therefore its vulnerability, and/or to enhance its adaptive capacity. Sustainable forest management, therefore, can play an important role in climate change adaptation. At present, however, many forests are not managed sustainably.

For adaptation to contribute to sustainable development, forest stakeholders at the international, national and local levels will need to agree on appropriate adaptation measures and policies and their implementation and monitoring. This will require a change from traditional top-down approaches towards multi-level information sharing, transparent decision-making, accountability, well-defined property rights and collaboration between stakeholders.

Research on forest adaptation to climate change is relatively recent; while many promising experiences exist, only a few studies have documented evidence of successful adaptation strategies. Climate change, however, appears to be progressing too quickly for decisions to be delayed pending the outcome of future studies. Irrespective of the uncertainties, societies can (and indeed must) make climate change mitigation and adaptation decisions now.

2 Forest Responses and Vulnerabilities to Recent Climate Change

Throughout human history, forest clearing for agriculture and other purposes has been a dominant factor in determining the extent and condition of the world's forests. Invasive species are also having a dramatic effect on the structure and function of many forest ecosystems. The rapid expansion of the global trade in forest products has stimulated investment in plantations and wood-processing plants, particularly in developing countries. In comparison with such factors, in most areas recent climate warming has had limited consequences for the forestry sector.

Nevertheless, over the past half-century climate change has affected many aspects of forest ecosystems including tree growth and dieback, insect outbreaks, species distributions, and the seasonality of ecosystem processes. The effects of recent climate change appear to have been greater in boreal forests than in other forests. In contrast, several factors that increase the vulnerability of forests to climate change appear to be more prevalent in subtropical and tropical forests. Available information, however, is insufficient to support a quantitative assessment of the ecological, social and economic consequences of recent forest responses to climate change.

The complexity of natural and human systems is a formidable barrier to quantifying climate change impacts and vulnerabilities. For example, forests are strongly influenced by tree growth rates (via slow processes) and disturbance regimes (via rapid processes).

Slow processes and rapid processes can be influenced simultaneously by a complex array of factors that includes several dimensions of climate (drought, temperature, wind, etc.).

This complexity notwithstanding, controlled experiments, local knowledge and other sources of information are helping to determine the mechanisms by which climate change can affect forest ecosystems. An understanding of such mechanisms will enable the identification and mitigation of some of the conditions that increase vulnerability in the forest sector to climate change.

In mid-latitude and high-latitude forests, for example, a warming of the climate is generally lengthening the growing season and increasing tree growth rates (thereby accelerating maturation processes). On the other hand, warming is also increasing biotic disturbance at those latitudes by increasing both the physiological activity and demographic potential of already-present pest species and the probability of invasion by non-indigenous herbivores, pathogens and plants. Adaptation to changes in maturation rates and the disturbance regimes are feasible via reasonably well-understood forest management tactics but will be complicated by interactions with other factors – such as land use change and invasive species – that are less easy to manage.

3 Future Environmental Impacts and Vulnerabilities

The Intergovernmental Panel on Climate Change has developed a large number of global emission scenarios for greenhouse gases and aerosols and corresponding scenarios for climate change using state-of-the-art climate models. Nevertheless, there is a lack of certainty associated with the future development of human societies, the responses of the climate system, and the effects of physical and biotic feedbacks.

For the purposes of this report, scenarios are grouped into four clusters on the basis of recent emission patterns: *unavoidable,* which can be used to assess minimal adaptation needs; *stable*, in which greenhouse gas concentrations approach a new equilibrium by 2100; and *growth* and *fast growth*, which correspond to business-as-usual emissions, *fast growth* representing developments since 2000, which involve unprecedented high emission levels.

Under most scenarios, climate change is projected to change the distribution of forest types and tree species in all biomes. Globally, under *growth* and *fast growth* scenarios, all forest ecosystems will have difficulty adapting to the impacts of climate change. Forest ecosystem services are expected to be significantly altered, particularly in submesic, semi-arid and arid climates, where productivity could decline to the extent that forests are no longer viable.

Several projections indicate significant risks that current carbon regulating services will be entirely lost, as land ecosystems turn into a net source of carbon beyond a global warming of 2.5°C (upper stable scenarios and beyond) or more relative to pre-industrial levels. Moreover, since forests also release large quantities of carbon if deforested or impacted by other degrading stressors, they exacerbate climate change further.

Under scenarios in the *stable* and *unavoidable* scenario clusters, productivity levels in currently temperature-limited or humid climates will stay constant or even increase. Nevertheless, species compositions are projected to be altered significantly: e.g. from boreal to mixed-deciduous, from mixed-deciduous to deciduous, from deciduous to savanna, or from boreal forest to grassland.

Under most scenarios, boreal forests will be particularly affected by climate change and they are eventually expected to shift poleward. There are major uncertainties, however, regarding the time required for this shift. Under *stable* and *growth* sce-

narios, forest productivity is expected to generally increase at the northern end of the biome but, under scenarios beyond *stable*, to decrease in the currently more productive southern forests due to the impacts of insects and fire, leading to large carbon emissions that will exacerbate climate change.

Under most scenarios, the temperate forests are likely to be less affected than other forest types by climate change. Large regional risks remain, however. Productivity is likely to increase in temperate forests closest to the poles and to decrease in temperate forests bordering the subtropics. Increasingly prevalent storms could cause major disturbances.

Under *growth* scenarios, productivity in some subtropical woodlands could increase due to the fertiliser effect of higher atmospheric CO_2 levels but, in other cases, rising temperatures, higher evaporation and lower rainfall could result in lower productivity. Droughts are projected to become more intense and frequent in subtropical and southern temperate forests, especially in the western United States, northern China, southern Europe, the Mediterranean and Australia. These droughts will also increase the prevalence of fire and predispose large areas of forest to pests and pathogens. In the subtropics the trend of increased fire is projected to wane in the latter part of the current century as lower rainfall reduces the availability of grass fuel. The subtropical domain contains many biodiversity hotspots that are at particular risk, even under scenarios stable.

The productivity of tropical forests is projected to increase where water is sufficiently available; in drier tropical areas, however, forests are projected to decline. Tropical forests, particularly rain forests, harbour the highest biodiversity of all land ecosystems; even moderate climate change (such as that projected in *unavoidable* and *stable* scenarios) would put some of this biodiversity at a considerable risk. According to the IPCC, roughly 20–30% of vascular plants and higher animals on the globe are estimated to be at an increasingly high risk of extinction as temperatures increase by 2–3°C above pre-industrial levels. The estimates for tropical forests exceed these global averages. It is very likely that even more modest losses in biodiversity would cause consequential changes in ecosystem services.

4 Future Socio-Economic Impacts and Vulnerabilities

Since climate change is expected to have significant impacts on the capacity of forests to provide vital ecosystem services, it could have far-reaching consequences for the well-being of people living in affected areas. Whether changes in a given region are positive or negative will depend critically on the region-specific nature of climate change: under current projections, forest productivity will rise in some regions and decline in others. The projected socio-economic impacts will present significant challenges for affected communities and societies, particularly the forest-dependent poor, who, in many countries, are already highly vulnerable to climate variability, changing political and economic circumstances, and other factors.

In the long term, climate change could increase the global supply of timber, although this will vary between and within regions. An expansion of global timber output is likely to lead to a reduction in timber prices; in some regions this will have negative effects on timber producers, but lower prices will benefit timber consumers.

Regions that, over the next 50 years, are likely to be particularly susceptible to the impacts of climate change on timber production are North America, Europe, Australia and New Zealand. Output in North America and Europe could decline due to the climate-induced dieback of existing stocks of timber trees and lower investments in timber production due to lower prices. These changes, however, are expected to be modest, with output increasing again in the second half of the century. In contrast, output in Russia is expected to expand modestly through the first half of the century, with stronger increases later in the century.

Fuelwood, charcoal and non-wood forest products (NWFPs) sustain or contribute to the livelihoods of significant proportion of the world's rural population. These products are particularly important to the forest-dependent poor in the tropical and subtropical regions where people rely on them for their livelihoods and for meeting domestic energy, food- and health-security needs. The impact of climate change on NWFPs is difficult to assess because of the high level of uncertainty about the ecological effects of climate change and because knowledge of the current and projected future demand for these products is incomplete.

The site-specific impacts of climate change on NWFPs are expected to impose additional stresses on people with limited adaptive capacity and a high degree of vulnerability. Local knowledge about and management practices for the sustainable production of NWFPs may be an important element in the response of forest-dependent people to climate change and can contribute to the development of adaptation strategies.

In regions with large forest-dependent populations, such as large parts of Africa, expected decreases in rainfall and increases in the severity and frequency of drought are likely to impose additional stresses on people. A decline in forest ecosystem services reduces the ability of forest-dependent people to meet their basic needs for food, clean water and other necessities and can lead to deepening poverty,

deteriorating public health and social conflict.

Forests provide many spiritual, aesthetic and recreational benefits; climate change adaptation responses, therefore, should take these into account. Few data are available, however, on the impacts of climate change on the cultural and spiritual values associated with forests or on recreation and ecotourism.

In many situations there are significant governance-related barriers to action that could exacerbate the impact of climate change on forests, including a lack of accountability, unclear property rights and corruption. Effective adaptation to climate change, therefore, involves reform in forest governance structures.

5 Current Adaptation Measures and Policies

Contemporary forest management and forest policies often serve multiple purposes and can incorporate measures to adapt to climate change, even if they are not primarily designed to do so. In many situations measures to tackle habitat destruction, forest fragmentation and forest degradation are compatible with efforts to adapt to climate change and to mitigate greenhouse gas emissions in the forest sector.

Local forest knowledge and traditional forest management practices have developed over a long time frame that encompasses considerable climatic variation. This knowledge can therefore have considerable value in contemporary climate change adaptation, particularly when applied to forest rehabilitation, restoration and the adaptive management of forests. However, while local and indigenous knowledge has been shown to be dynamic, its capacity to adapt quickly enough to the more dramatic climate change impacts cannot be assumed, especially in many parts of the world where it is already disappearing for a number of reasons. The recognition and preservation of traditional forest-related knowledge and its translation into the language of formal forest science are important steps towards adaptation and application of traditional forest-related knowledge to new or changing environmental, social and economic contexts.

To date, forest-sector responses to climate change have mostly been reactive. The diverse values and interests of stakeholders, which can impede efforts to reach consensus on adaptation goals, need to be addressed in efforts to encourage proactive adaptation. Proactive strategies ('anticipatory adaptation') must also deal explicitly with the uncertainty inherent in projections of future climate change and their impacts. Adaptive management allows the simultaneous implementation of alternative measures so that their efficacies can be compared.

Forest policy programmes and instruments can support forest owners and forest managers to take the actions necessary to ensure sustainable forest management under changed climatic conditions. National Communications (NCs) and National Adaptation Programmes of Action (NAPAs) produced for the United Nations Framework Convention on Climate Change provide an overview of existing regulatory, economic and informational policy measures for adaptation within the tropical, subtropical, temperate and boreal regions. Overall, existing policies reflect the differing environmental and socio-economic priorities and circumstances of countries and regions. Although there are many similarities, country/regional differences have also led to the formation of contrasting policies. Despite these differences, most forest policies advocate sustainable forest management as a mechanism for climate change adaptation, and it is commonly promoted through national forest laws. Most NCs and NAPAs, however, rely on a generalised concept of sustainable forest management and do not identify the specific changes that need to be incorporated into management strategies and policies. Existing policies also tend to be reactive to observed events rather than proactive.

6 Management for Adaptation

Adaptation measures are needed to ensure that the ecosystem services provided by forests are maintained under future climates. The scientific basis for such measures varies across major forest types, as does their potential effectiveness. In particular, the measures chosen for any given forest will depend on the local situation and the expected nature of future climate change. As a result, there are no universally applicable solutions.

The choice of adaptation measures will be determined not only by the likely changes occurring in a forest, but also by the management objectives for the forest (which might change in light of climate change), its past management history, and a range of other factors. A critical aspect of any adaptation framework will be to ensure that local managers have sufficient flexibility to choose the most appropriate suite of management measures for their conditions.

Forest management actions taken to adapt to climate change can be consistent with sustainable forest management (SFM). SFM is a continuously evolving concept designed to ensure that forests continue to provide a range of ecosystem services. Forests are social-ecological systems that involve both nature and society. Sustainable forest management, therefore, serves both forest ecosystems and the people and societies that benefit from the provision of forest ecosystem services. The current failure

to fully implement sustainable forest management is likely to limit the ability of forests to adapt to climate change.

The uncertainties associated with climate change emphasise the need to identify robust forest management strategies – those that are likely to achieve the objectives of sustainable forest management in a wide range of potential future climate conditions. Such strategies must also be flexible and responsive to new information and therefore should incorporate the principles of adaptive management. They should take advantage of the opportunities that climate change can present in some regions, such as increases in forest productivity.

In all scenarios and across all main forest types it is very likely that the frequency and intensity of storms, fire, insect attack and disease will change, with increases in some areas. The mitigation of undesirable impacts will require extensive communication networks and monitoring schemes at the regional and national levels, as well as specific management practices (e.g. controlled burning and sanitary cuts) at the local level. These measures, in turn, will require considerable investments in infrastructure (e.g. related to communications, fire detection and transport), training and equipment.

A laissez-faire approach to forest management is inappropriate for effective climate change adaptation; if specific management values are to be maintained, active management will be required. A failure to take action now is likely to result in increased costs in the future. Managers need to be proactive, imaginative and adaptable. The need for more management implies additional costs; it is important, therefore, that, particularly in developing countries, opportunities to finance these costs through payments for the climate change mitigation services provided by forests are realised.

A key management strategy applicable to all forests is adaptive co-management; this is a systematic process that recognises the importance of stakeholder cooperation and aims to continually improve management policies and practices by monitoring and learning from the outcomes of operational programmes. For effective adaptation, policies and regulations must be sufficiently flexible to facilitate adaptive co-management, and there needs to be a recognition that mistakes will be made.

Within the context of the uncertainty associated with climate change, adaptive co-management could help forest managers to adjust the structure and, consequently, the functioning of forest ecosystems to resist the harmful impacts of climate change and to take advantage of the opportunities created by climate change. Although many current forest management practices can facilitate the adaptation of forests to climate change they may be insufficient because they were developed under a climate that might be substantially different from the future climate.

In the long term, unmitigated climate change would most likely exceed the capacity of natural, managed and human systems to adapt. Adaptation measures, therefore, will only buy ecosystems additional time to adjust to the changing climate until broad global action to reduce greenhouse gas emissions takes effect.

7 Governance and Policies for Adaptation

Traditional forms of forest governance that focus on hierarchical, top-down policy formulation and implementation by the nation state and the use of regulatory policy instruments are insufficiently flexible to meet the challenges posed by climate change. Moreover, policies in other sectors, especially agriculture, transportation and resource development, will continue to have significant impacts on forests, requiring improved inter-sectoral coordination that is difficult to achieve through top-down policy-making.

The high level of uncertainty associated with the impacts of climate change, the complexity of the problem, the need for better inter-sectoral coordination, and the wide range of new actors and interest groups who are expected to become involved in policy-making for climate change adaptation all pose challenges for policy design. These challenges can be met by new and hybrid modes of governance that make greater use of policy networks and by adopting a flexible mix of policy instruments.

Network governance embraces the participation of multiple actors in policy formulation and implementation and turns the presence of a diversity of actors from a problem to a solution. Flexible mixes of policy instruments, which use traditional regulation to backstop a variety of incentives, voluntary agreements and knowledge-based instruments, enable experimentation in the face of uncertainty and the rapid international convergence on best practices.

National forest programmes are the core instruments of new forest governance arrangements at the national level: they can promote the adaptation of forests to climate change by reinforcing the use of sustainable forest management as a mechanism for reducing deforestation and forest degradation. The goal of adaptation to climate change should be added to the existing economic, ecological and social goals of sustainable forest management. In this way, adaptation can be promoted without compromising the overarching commitment to sustainability that drives national forest programmes.

Action at the international level presently consists of a number of poorly coordinated programmes directed mainly at reducing deforestation and mitigating climate change rather than at addressing the

full range of climate-change adaptation issues and options. Better linkages between sustainable forest management and climate-change adaptation, and positive interactions between the international forest regime (as represented by the United Nations Forum on Forests and the Non-Legally Binding Instrument on All Types of Forest – NLBI, the Convention on Biological Diversity and the United Nations Framework Convention on Climate Change) should be facilitated by adding a fifth global objective to the NLBI that specifically refers to climate-change mitigation and adaptation. From a policy design perspective, the major shortcomings of the United Nations Framework Convention on Climate Change and its Kyoto Protocol are the dominant role of mitigation as a policy goal and the lack of appropriate funding.

Forest adaptation policies should not ignore the many drivers of forest change that originate in other sectors: developments in agriculture, energy (e.g. the growing of biofuel crops to replace fossil fuels), transportation, conservation and even macroeconomic policies can have dramatic effects on the incentives to destroy or degrade forests. Improving inter-sectoral coordination would be a first step towards an effective, integrated approach to land use and land management.

There is a substantial shortfall in the provision of funding to reduce deforestation to the levels required, and the available funds are often poorly targeted. For these reasons a broad approach to financing is needed, one that does not rely on a single, one-size-fits-all mechanism. In spite of the risk of negative interactions between different international regimes, it is important to continue to look for synergies with climate change programs for meeting the projected funding shortfall for adaptation, while simultaneously seeking to restore official development assistance funding for SFM under the NLBI. Evaluations have shown that financial incentives are very effective policy levers for promoting sustainable forest management when used in combination with regulation and information. For financial incentives to work, therefore, it will be necessary to continue to support research that will reduce the uncertainties associated with the impacts of climate change on forests and to improve knowledge about the management options that promote successful adaptation.

Adaptation should not be viewed independently of mitigation. Large reductions in fossil-fuel emissions and halt to deforestation are needed to curb climate change and to ensure that forests retain their adaptive capacities.

Key Messages

- Climate change over the past half-century has already affected forest ecosystems and will have increasing effects on them in the future. The carbon-regulating services of forests are at risk of being lost entirely unless current carbon emissions are reduced substantially; this would result in the release of huge quantities of carbon to the atmosphere, exacerbating climate change.
- Climate change can increase the supply of timber in some regions although there will be considerable temporal variations.
- The impacts of climate change on forest goods and services will have far-reaching social and economic consequences for forest-dependent people, particularly the forest dependent poor. Adaptation measures must go beyond single technical solutions and address also the human-institutional dimensions of the problem.
- Sustainable forest management is essential for reducing the vulnerability of forests to climate change. The current failure to implement it limits the capacity of forests and forest-dependent people to adapt to climate change. To meet the challenges of adaptation, commitment to achieving the goals of sustainable forest management must be strengthened at both the international and national levels.
- There is no universally applicable measure for adapting forests to climate change. Forest managers should, therefore, have sufficient flexibility to deploy the adaptation measures most appropriate for their local situations.
- Flexible approaches to policy design are needed that are sensitive to context and do not rely on a single, one-size-fits-all mechanism. New modes of governance are required that enable meaningful stakeholder participation and provide secure land tenure and forest user rights and sufficient financial incentives.
- More research is required to reduce current uncertainties about the climate-change impacts on forests and people and to improve knowledge about management and policy measures for adaptation. Nevertheless, despite the limitations of current knowledge, climate change is progressing too quickly to postpone adaptation action pending the outcomes of future studies.
- Even if adaptation measures are fully implemented, unmitigated climate change would, during the course of the current century, exceed the adaptive capacity of many forests. Large reductions in greenhouse gas emissions from fossil fuels and deforestation are needed to ensure that forests retain their mitigative and adaptive capacities.