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ADAPTATION OF FORESTS AND PEOPLE TO CLIMATE CHANGE
– A Global Assessment Report

Prepared by the Global Forest Expert Panel on Adaptation of Forests to Climate Change

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Preface

This book is the first product of the Collaborative Partnership on Forests' Global Forest Expert Panels (GFEP) initiative. GFEP is a new mechanism for providing objective and independent scientific assessments of key forest-related issues to support international processes and decision-making at the global level. It is led and coordinated by the International Union of Forest Research Organizations (IUFRO).

Policy makers recommended making adaptation of forests to climate change the subject of the first scientific assessment. Accordingly, an Expert Panel on Adaptation of Forests to Climate Change was formed by the GFEP Steering Committee in late 2007 to carry out this assessment. This Expert Panel consists of 35 scientists and experts from different forest-related disciplines and different parts of the world. About the same number of scientists contributed to the assessment as reviewers. The results of their voluntary collaboration between February 2008 and February 2009 are presented in the eight chapters of this book. The chapters have been prepared by Coordinating Lead Authors with teams of Lead Authors and Contributing Authors. They are based on a common conceptual framework and follow a logical sequence. Nevertheless, the chapters have been written so that they can be read independently from each other. As a result, a certain level of repetition may occur. Conclusions from individual chapters are presented at the end of chapters.

Based on the main findings of the assessment, a policy brief titled "Making forests fit for climate change – A global view of climate-change impacts on forests and people and options for adaptation" has been prepared especially for policy and decision makers.

Given the wide scope of the topic adaptation and the very limited time available for the assessment, our book cannot cover every issue related to the adaptation of forests and people to climate change. The assessment also reveals that there are still major gaps in knowledge about the impacts of climate change on forests and people and about how adaptation actions can best be tailored to local conditions. Nevertheless, it is my sincere hope that this book will contribute to the discussion on and development of effective adaptation strategies while at the same time providing a robust basis for further research on the adaptation of forests and people to climate change.

This book is dedicated to one of our Lead Authors, our friend and colleague David Karnosky who deceased in October 2008.

Risto Seppälä
Chair of the Expert Panel on Adaptation of
Forests to Climate Change

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Furthermore, we would like to thank the GFEP Steering Committee for providing overall guidance and generous in-kind support: the International Union of Forest Research Organizations (IUFRO), the Center for International Forestry Research (CIFOR), the Food and Agriculture Organization of the United Nations (FAO), the World Agroforestry Centre (ICRAF), the Secretariat of the Convention on Biological Diversity (CBD), and the Secretariat of the United Nations Forum on Forests (UNFF).

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We also thank the Secretariat of the Intergovernmental Panel on Climate Change (IPCC) for its valuable advice for our assessment.

Our particular gratitude goes to Seppo Oja for designing and preparing the layout of this publication. Furthermore, we thank Anthony Lambert, Alastair Sarre and Gerda Wolfrum for language editing. Finally, we would like to express our gratitude to all other people and organizations who have contributed to this publication in one way or the other.

The editors:

Risto Seppälä, Alexander Buck and *Pia Katila*

March 2009

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Acronyms and Abbreviations

AF	Adaptation Fund
AHTEG	Ad Hoc Technical Expert Group on Biodiversity and Climate Change
AOGCM	Atmosphere-Ocean General Circulation Models
APF	Adaptation Policy Framework
AR4	Intergovernmental Panel on Climate Change Fourth Assessment Report
ASRD	Alberta Sustainable Resource Development
BC	British Columbia
BCMOF	British Columbia Ministry of Forests and Range
C&I	Criteria and Indicators
CABI	Centre for Agricultural Bioscience International
CBD	Convention on Biological Diversity
CCIAV	Climate Change Impact, Adaptation and Vulnerability
CDM	Clean Development Mechanism
CFM	Community Forest Management
CIFOR	Centre for International Forest Research
CIF	Climate Investment Funds
COHAB	Co-Operation on Health & Biodiversity
COP	Conference of Parties
DFID	United Kingdom´s Department for International Development
DGVM	Dynamic Global Vegetation Model
ECE	United Nations Economic Council for Europe
ENSO	El Nino-Southern Oscillation
ET	Emissions Trading
ETS	Emissions Trading System
EU	European Union
FAO	Food and Agricultural Organization of the United Nations
FCPF	Forest Carbon Partnership Facility
FLEGT	Forest Law Enforcement, Governance and Trade
FRA	Forest Resources Assessment
FSC	Forest Stewardship Council
GATT	General Agreement on Tariffs and Trade
GCGCC-MST	General Coordination on Climate Change-Ministry of Science and Technology, Brazil
GCM	General Circulation Model
GDP	Gross Domestic Production
GEF	Global Environmental Facility
GHG	Green House Gas
IAITPTF	International Alliance of Indigenous and Tribal Peoples of Tropical Forests
ICRAF	World Agroforestry Centre
IFF	Intergovernmental Forum on Forests
IFRC	International Federation of Red Cross and Red Crescent Societies
ILO	International Labour Organization
INBAR	International Rattan and Bamboo Network
IPCC	Intergovernmental Panel on Climate Change
IPF	Intergovernmental Panel on Forests
ITTA	International Tropical Timber Agreement
ITTO	International Tropical Timber Organization
IUFRO	International Union of Forest Research Organizations
JI	Joint Implementation
KP	Kyoto Protocol
LAI	Leaf Area Index
LCA	Life Cycle Analysis
LDC	Least Developed Countries
LDCF	Least Developed Countries Fund

LULUCF	Land Use, Land-Use Change and Forestry
MEA	Millennium Ecosystem Assessment
MPB	Mountain Pine Beetle
NAFTA	North American Free Trade Agreement
NAPA	National Adaptation Programmes of Action
NAS	National Adaptation Strategy
NC	National Communication
NFP	National Forest Programme
NGO	Non-Governmental Organization
NLBI	Non-Legally Binding Instrument
NPP	Net Primary Production
NWFP	Non Wood Forest Product
ODA	Official Development Assistance
OECS	Organization of Eastern Caribbean States
OMAFRA	Ontario Ministry of Agriculture, Food and Rural Affairs
PEFC	Programme for the Endorsement of Forest Certification schemes
PES	Payments for Environmental Services
PFT	Plant Functional Types
REDD	Reducing Emissions from Deforestation and forest Degradation
SARS	Severe Acute Respiratory Syndrome
SBI	Subsidiary Body for Implementation
SBSTA	Subsidiary Body for Scientific and Technical Advice
SCBD	Secretariat of the Convention on Biological Diversity
SCCF	Special Climate Change Fund
SFM	Sustainable Forest Management
SIDA	Swedish International Development Cooperation Agency
SPA	Strategic Priority on Adaptation
SRES	Special Report on Emission Scenarios
TAR	Intergovernmental Panel on Climate Change Third Assessment Report
TIES	International Ecotourism Society
UNCED	United Nations Conference on Environment and Development
UNDESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational Scientific and Cultural Organisation
UNFCCC	United Nations Framework Convention on Climate Change
UNFF	United Nations Forum on Forests
US	United States
USA	United States of America
USD	United States Dollar
USFS	United States Forest Service
VPA	Voluntary Partnership Agreement
WCMC	World Conservation and Monitoring Centre
WHO	World Health Organisation
WTO	World Trade Organization

UNITS

The metric system is used in this publication

t = tonne (10^3)
M = mega (10^6)
G = giga (10^9)
P = peta (10^{15})
ha = hectare (100 ha = 1 km^2)
a = year

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* scenarios, 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 macro-economic 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.

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

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1.1 Justification

The Intergovernmental Panel on Climate Change (IPCC 2007a) presents evidence that the climate is changing. Emission of greenhouse gasses is the main anthropogenic cause of climate change (IPCC 2007a), and the degree to which societies are able to reduce these emissions (defined as mitigation, see glossary) will affect the size of future changes. Regardless of mitigation activities implemented, today or in the near future, the planet will still experience a certain degree of change due to historical emissions and inertia in the climate system. Sea level rise, melting of the polar ice caps and increased frequency of severe fires, pests and storms are some of the effects that have already been attributed to changes in climate and its variability (IPCC 2007a; see also Chapter 2 for a more extensive discussion of past impacts and vulnerabilities). Some of these phenomena have caused serious social stress and have shown the need to be better prepared for future changes. Because of this, it is essential that individuals, societies and institutions are aware of the likely changes and have strategies in place to adapt to a changing climate.

Forests and the goods and services they provide are essential for human well-being. The assessment of the likely impacts of climate change on forests and forest-dependent people and their vulnerabilities are thus important for enhancing climate change adaptation. It also forms the basis for developing adaptation options to avoid harmful effects of climate change and to take advantage of opportunities provided by it. This report provides an assessment of the current knowledge concerning the following questions:

- What are the interrelations between forest ecosystems and the services provided by them, and the climate?
- What are the past and future climate change impacts on and vulnerabilities of forest ecosystems and the people that depend on them?
- What are the management and policy options for adaptation?

The present report is based on information and knowledge published in the scientific literature as well as from reliable sources of traditional and technical knowledge. It consists of three parts: an *introduction*, which presents the conceptual framework used for the assessment (Chapter 1). The second part deals with *past and future impacts and vulnerabilities*. Past observations of impacts, vulnerabilities and adaptations are discussed in Chapter 2. The future environmental and socio-economic impacts and vulnerabilities are discussed in Chapters 3 and 4 respectively. In the third part, current *adaptation measures and policies* are summarized in Chapter 5 and a range of forest management and forest policy options for adaptation are presented in Chapters 6 and 7. Chapter 8 sums up the main conclusions, knowledge gaps and research needs.

The report aims to provide knowledge for enhancing the adaptive capacity of both forests and people to the impacts of climate change. At the same time, scientific input into policy processes cannot be limited to the production of a written report, but rather has to be seen as a socially interactive process (Guldin et al. 2005). Consequently, the authors of this report expect that through their involvement in this process they may contribute to the development of strategies with key actors, raise the visibility of adaptation of forests to climate-change impacts on the policy agenda of the UNFF (United Nations Forum on Forests) and other international policy fora.

1.2 Concept of Adaptation

In this report, IPCC's (Intergovernmental Panel on Climate Change) universally recognized definition of adaptation is followed (IPCC 2007b, p. 869, see also glossary): 'Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities'. Adaptation may be anticipatory or reactive, autonomous or planned. Biological adaptation is autonomous and reactive: organisms respond over time to changing conditions. People, on the other hand, may show autonomous adaptation in response to changes, or plan for adaptation either in response to changes (both reactive) or to reduce vulnerability or enhance resilience in anticipation of expected changes (anticipatory adaptation) (Adger et al. 2007). For example, planning to strengthen water works in anticipation of expected sea-level rise is anticipatory adaptation. Actual adaptations in forests and forestry practices are mainly reactive and autonomous (see Chapter 2) and depend on locally experienced changes and vulnerabilities. This report, however, stresses that the expected changes (Chapter 3 and 4) require planned anticipatory adaptation (Chapters 5, 6 and 7) partially based on learned lessons and slight adjustments of current practices, but in other cases requiring new, out of the box thinking.

Planned adaptation is based on expected changes. Projections of such changes on a local level may not be very accurate (see also Chapter 3) or may be poorly understood. This introduces the risk of maladaptation. Strategies to reduce the risk of maladaptation are discussed in chapters 5, 6 and 7.

Many adaptation strategies focus on reducing vulnerability, or strengthening the ability to capture the benefits from the effects of change. Vulnerability is therefore strongly related to adaptation. It has been defined (Metzger et al. 2006, IPCC 2007b, see also glossary for more detailed definition) as a function of exposure, sensitivity and adaptive capacity. Adaptation strategies oriented at reducing vulnerability can therefore include (Adger et al. 2007):

Altering the exposure of a system, through for example, investing in hazard preparedness and early warning systems, such as seasonal forecasts.

Reducing the sensitivity of the affected system (degree to which a system is affected, see glossary) through, for example, planting hardier crops, increasing reservoir storage capacity, or ensuring that infrastructure in flood-prone areas is constructed to allow flooding.

Increasing the resilience (ability to absorb disturbances, see glossary) of social and ecological systems, through specific measures which enable populations to recover from loss.

The potential vulnerability of a system to climate change will depend on that system's ability to adapt appropriately in anticipation of the hazard (Brooks et al. 2005), which will depend on the adaptive capacity of the system. Adaptive capacity is a function of different elements, including the ability to modify exposure to risks associated with climate change, to absorb and recover from losses stemming from climate impacts, and to exploit new opportunities that arise in the process of adaptation (Adger and Vincent 2005). Forest ecosystems with greater diversity usually show a greater adaptive capacity (SCBD 2003, Fontaine et al. 2005), being able to adapt in a variety of ways to different changes, although large disturbances may affect highly diverse systems as much as those of low diversity, preventing the system from recovering its original state (Walker et al. 2006).

It is often assumed that societies with a higher level of economic development have a higher adaptive capacity. However, evidence from traditional societies demonstrates that the capacity to adapt in many senses depends more on experience, knowledge and dependency on weather-sensitive resources: economically little developed forest-dependent indigenous people in the south-west Amazon, for example, may have a greater adaptive capacity than the economically more sophisticated people living in the Andes, who rely on rain-dependent agricultural practices. Adaptation can involve both building adaptive capacity and implementing adaptation decisions, i.e. transforming the capacity into action (Adger et al. 2005).

1.3 Conceptual Framework for the Report

1.3.1 Forest Ecosystem Services and Human Well-Being

Humans use forests for many purposes, and the products derived from forests, and their benefits, are referred to as 'forest goods and services' (MEA 2005). Generally the services fall into four groups: supporting, provisioning, regulating, and cultural services (Diaz et al. 2005, Fischlin et al. 2007) (Figure 1.1). Although forest goods are the result of provisioning services, they are usually mentioned separately, being more tangible than the other services. This value chain includes wood and wood products such as fuelwood, paper, charcoal and wood structural products, and non-wood products (foods and plant products) such as rattan, mushrooms, nuts and fruits, honey, bushmeat, rubber and biochemicals. Forest services refer to benefits provided to humans, many of which have so far no readily assigned economic value. The

Erkki Oksanen: Boreal forest, Finland

Photo1.1 Forests provide multiple tangible and intangible benefits. The same forest area can for example provide wood, non-wood forest products such as wild berries, clean water and an environment for recreation.

main services from forest ecosystems include: habitat provision, clean water, flood protection, carbon sequestration and storage, climate regulation, oxygen production, nutrient cycling, genetic resources for crops, and spiritual, cultural, recreational and tourism values.

While some of these goods and services may also be provided for by other ecosystems (Campos et al. 2005, Fischlin et al. 2007), the contribution of forest ecosystems to these goods and services has a significant economic value, with global trade in primary wood products valued at around USD189 billion in 2005 (FAO 2006). Nevertheless, many of the ecosystem services and a large part of the non-timber forest products are not accounted for in national product calculations (section 4.5 in Fischlin et al. 2007) but yet have value. For example, carbon sequestration is a service provided by plants and algae – a part of biodiversity – occurring in forests. While this service had no assigned value until the 1990s, in 2008 the carbon market grew to a worth of over USD 60 billion (Bull 2008). Another example of a forest good that often has no monetary value and is rarely included in calculations of national product is clean water. Regardless of whether or not forest goods and services are assigned economic values, they provide many people with a source of livelihood and generally directly affect human well-being and are especially important for the large number of forest-dependent communities (Kaimowitz 2002, CBD 2008).

Biodiversity is a cornerstone for the provision of many of the ecosystem services (Figure 1.1) (Campos et al. 2005, CBD 2008), although many of the supporting and some of the regulating services are necessary for maintaining biodiversity. The relationship between production and species diversity is, however, not as well understood. For example, not all species contribute equally within systems – the loss of an individual tree species from a forest ecosystem does not necessarily result in a reduction in productivity, especially in diverse systems (Gitay et al. 2002, SCBD 2003). Nevertheless, the functional components of biodiversity are linked to ecosystem production (Diaz and Cabido 2001, Diaz et al. 2005) and the loss of key functional species from forest systems will generally reduce certain goods and services produced by that system (Hooper and Vitousek 1997, Tilman et al. 1997, Diaz et al. 2005). Differences in composition, structure and diversity of forests may therefore mean that forests show differences in the provision of goods and services.

Global forests are highly diverse with many distinct forest types recognized under various classification schemes. The abundance of forest types is related to latitude and altitude, with greater diversity

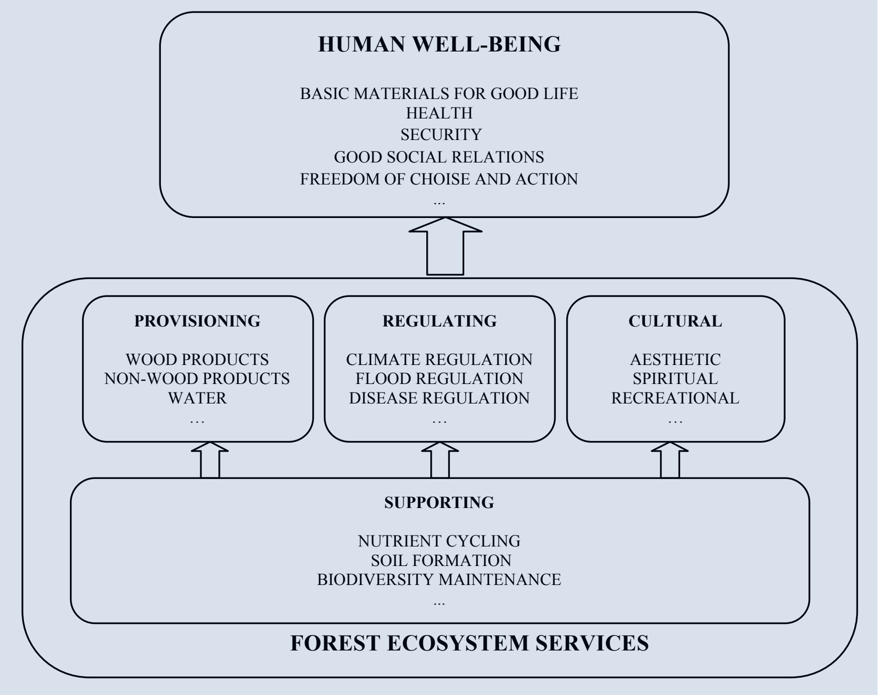

Figure 1.1 Ecosystem goods and services and their relation to well-being (modified from MEA 2005).

Table 1.1 Forest types recognized and number of ecoregions identified in Olsen et al. (2001).

Forest type	Ecoregions
Tropical and subtropical moist broadleaf forest	231
Tropical and subtropical dry broadleaf forests	54
Tropical and subtropical coniferous forests	17
Temperate broadleaf and mixed forests	84
Temperate coniferous forest	53
Mediterranean forests, woodlands and shrub	39
Boreal forests/Taiga	28
Mangroves	19

at low latitudes and at lower elevations. United Nations Environment Programme – World Conservation and Monitoring Centre produced a map based on 26 forest types divided between tropical forests (13 plus 2 plantation types) and non-tropical forests (9 plus 2 plantation types) (UNEP-WCMC 2000). For Forest Resources Assessments, the FAO (Food and Agriculture Organization of the United Nations) uses 13 forest types: 4 tropical, 3 subtropical, 3 temperate and 3 boreal (FAO 2001). Within each forest type, regardless of the classification hierarchy used, there are multiple ecoregions (Olsen et al. 2001) (Table 1.1.). Tropical regions maintain about 2.5 times the number of recognizable ecoregions than temperate regions and 10 times the number found in boreal forests, indicating their high level of species richness and diversity.

Ecosystem services and their relation to the constituents of well-being (Figure 1.1) may vary between different ecoregions, just as exposure, sensitivity and adaptive capacity may also differ, in turn affecting the optimum recommendations for forest management and policies. In some ecoregions flood regulation may be the main service. In other ecoregions, it might be providing personal safety and allowing local people to obtain basic material for a good life from their immediate surroundings. Or primary production and the subsequent provision of fuelwood and timber may be the most important services for local human well-being. However, for the purposes

John Parrotta: Western Ghats, Kerala, India

Photo 1.2 Biodiversity is the foundation for the provision of many ecosystem services such as water regulation. At the same time many of the supporting services and some of the regulating services are needed for maintaining biodiversity.

of this report it is impossible to describe vulnerability, management and policy options for each different ecoregion. The Expert Panel has therefore opted for a very rough global approach, recognizing only four global forest types, following the FAO classification: tropical, sub-tropical, temperate and boreal (see Chapter 3 for a more detailed description of each forest type and their main goods and services). Further specifications will be made only in those cases where evidence of different approaches within these global forest types exists.

While a relatively large amount of information is available on the effects of climate change on these four different global forest types (Chapter 3) and conclusions can be drawn on general strategies per forest type (Chapter 5), no correspondingly wide information is available by forest type on the impacts on and vulnerabilities of social systems, nor on specific adaptation options. As a result, Chapters 4 and 6 concentrate on services, rather than forest types, referring to forest types only where sufficient information is available. Chapter 7 analyses the effectiveness of policy instruments at the national and international level for forest adaptation and describes what steps can be taken to strengthen forest governance for the provision of forest ecosystem services.

1.3.2 Climate Change and Forest Ecosystem Services

Forests play an important role in the emission of greenhouse gases: about 20% of the total carbon emissions come from forest cover loss and forest degradation (Houghton 2003, Houghton 2005, Denman et al. 2007, IPCC 2007c). In countries experiencing high rates of forest loss, such as Brazil, land-use change was estimated to contribute up to 75% of all CO_2 emissions in 1994 (GCGCC-MST 2004). Carbon sequestration and carbon storage are important forest ecosystem services oriented at reducing or compensating for these emissions (mitigation), and the loss of this service may influence the level of climate change. Avoiding deforestation (avoids emission) and increasing the forest biomass (carbon sequestration) have therefore great mitigation potential (Kanninen et al. 2007, Nepstad et al. 2007), but their success in doing so will also depend on the sensitivity and adaptive capacity of the resulting natural systems (Guariguata et al. 2007).

Forests and their conservation or loss influences climate, and climate in its turn is a key driver of the changes in forest ecosystems. Changing CO_2 levels in the atmosphere, changing temperatures and precipitation, or changes in the frequency of extreme events, may affect forests in a number of different ways (e.g. temperature and moisture affect growth rates, changes in natural disturbance regimes may affect species composition). Together with existing socioeconomic processes (e.g. deforestation, forest fragmentation, other forms of habitat loss, population growth, income growth, urbanization), these changes may result in changes in the ecosystem services provided by forests (see Chapter 3).

Climate change has the capacity to cause ecosystems to move to new states – for example, from spruce forest to pine forest, or from forest to savannah (Nobre and Oyama 2003, Fischlin et al. 2007, Mendes 2007, Nepstad 2007). Maintaining a dynamic equilibrium and resilience over time and space is important in the continued delivery of ecosystem goods and services, independent of the level of emissions expected. In forests, this dynamic equilibrium often exists over time and across the forest landscape, as a forest undergoes both slow and fast changes but continues to supply goods and services (Walker et al. 2006, Drever et al. 2006). Resistance to change is an emergent property of forest ecosystems (Drever et al. 2006).

Ecological theory about functional redundancy predicts that a relationship exists between the capacity for resistance to environmental change and the diversity within a system (Chapin et al. 1996, Diaz et al. 2003, Walker et al. 2006). For example, a monoculture plantation may be highly susceptible to a root rot, whereas a diverse forest ecosystem with many tree species is less prone to decline from the same pathogen. Hence, highly diverse systems tend to be more resistant to change than simpler systems (SCBD 2003, Fontaine et al. 2005), including resistance to invasion by alien species (Mack et al. 2000). In part, this stability is due to the level of connectedness within the system and the lack of available niches in diverse systems (Hooper et al. 2005, Diaz et al. 2005), and also to the level of genetic variability that can allow systems to adapt to change (Joshi et al. 2001, Davis and Shaw 2001, Davis et al. 2005).

The relationship between biodiversity and resilience is unclear (Schmid et al. 2002), however; systems that have moved to new states as a result of some perturbation find it difficult to recover because of changes in biodiversity and in associated ecosystem processes (Walker et al. 2006, Gunderson and Holling 2002). Such highly altered systems are unlikely to continue to provide the same levels or types of goods and services as they did prior to disturbance, e.g. as when forest changes to grassland (SCBD 2003, Diaz et al. 2005). Hence, protection of the biodiversity in the system is an important means to assist communities to adapt to climate change (Diaz et al. 2005, Drever et al. 2006).

The scale and intensity of ecosystem change will depend on the level of exposure as well as on the adaptive capacity of the forests (e.g. high diversity, adaptation to fire, nature of ecological processes). It is therefore important to consider the different emission scenarios of the IPCC (2007a), each of which may imply different levels of exposure. In Chapter 3 four scenario clusters are presented to simplify this vast range of options for the discussions in this report: unavoidable, stable, growth and fast growth.

Adaptation involves changes in how services are being affected by climate change, as well as in the way that services relate to human well-being. Generally, when climate conditions change, as they have often in the past, depending on the severity of the change, species must adapt (genetically or behaviourally) or migrate to follow and find suitable conditions (Jansen et al. 2007, Fischlin et al. 2007). Forest ecosystems can tolerate some change (Fischlin et al. 2007) but if resistance is overcome this may have severe consequences for the nature of, in particular, the supporting services as well as for the availability of the other services locally and in some cases also at the regional and global level (Diaz et al. 2005, 2006).

These changes may have a negative or positive impact on the constituents of well-being, depending also on the nature of the relation between service and constituent as well as on the vulnerability of the social system studied (Figure 1.1 and Chapter 4). Some of the relations between services and constituents of well-being are stronger than others (for example, the relation between provisioning services and basic material for good life and health, or those of the regulating services with security, basic material and health), and changes in these services may have a greater impact on human well-being.

Current socioeconomic processes are biased towards modifying the relation between provisioning goods and basic materials for a good life (Figure 1.1), but future adaptation practices will need to address all services as well as their relations to the different constituents and the balance between those constituents. Chapters 5, 6 and 7 summarize existing experiences on anticipatory and reactive adaptation strategies to reduce exposure (e.g. mitigation, windbreaks), reduce sensitivity (e.g. less change with same exposure, or less dependency on one or few forest ecosystem services) or increase adaptive capacity (e.g. increased technology, diversity of genetic resources, governance that balances individual freedoms of choice and action).

1.3.3 Forest Users, Vulnerabilities and Adaptations

The variety of forest users in the world is enormous. Broad groups of users are society, governments and companies as well as private forest owners and lo-

Matti Nummelin: Belayara, Niger

Photo 1.3 The vulnerability and priorities of different forest users in relation to changes in the environment vary. For the poorest the immediate priority may be to secure livelihoods and protect assets from climate and other risks.

cal communities. The last category can be roughly subdivided into those who live in the forests, those who live in an area with an active agricultural frontier, and those in areas where the agricultural frontier has passed many years ago. Each of these groups show different vulnerabilities to changes in their environment, which may also differ according to their geographical location and cultural background. The factors that affect vulnerabilities (as a function of exposure, sensitivity and adaptive capacity) may also vary widely between the user groups. For example, poorer people with low geographic mobility will be more vulnerable to the impacts of climate change and need tailor-made strategies of forest management and policies to reduce their vulnerability (Reid and Huq 2007).

Which adaptation options, or combinations of adaptation options, are chosen, will depend largely on vulnerabilities, which are among other things determined by the social and economic situation of households and communities, their physical location, their networks of relationships (social and economic) and their access to resources and power. This provides us with an enormous array of adaptation options that cannot all be dealt with in this report. Chapters 6 and 7, therefore, should be read keeping in mind the main target groups at which adaptation strategies and specific options are directed.

Sustainable forest management (SFM) has been described by the UN (United Nations) (UN 2007, see also glossary) as 'a dynamic and evolving concept, aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations'. Forest management is one of several factors that, together with land-use change, may influence the effects of climate change in forests (Fischlin et al. 2007). SFM aims to contribute to sustainable development. The IPCC Fourth Assessment Report concluded that sustainable development can reduce vulnerability to climate change by increasing resilience and enhancing adaptive capacity (Yohe et al. 2007, Adger et al. 2007). SFM can thus play an important role in adaptation to climate change, in particular where SFM is embedded in an array of sustainable land uses within a landscape and where it considers the different expectations, vulnerabilities and capacities of the different actors within that landscape (Table 1.2).

While the influence of climate change on forest ecosystems poses new questions about how SFM can be achieved, the principles and practice of SFM embodies many of the activities that will be required to respond to the effects of climate change on forests (Ogden and Innes 2007, Spittlehouse and Stewart

Table 1.2 Illustration of differences in forest dependence, vulnerability to the impacts of climate change and factors affecting the vulnerability of different forest user groups using the example of the State of Pará, Brazil (own elaboration based on information from Galloway et al. 2005, Lentini et al. 2005, Chomitz 2007, Mendes 2007, Nepstad 2007, Sabogal et al. 2008).

User group	Main goods and services	Level of vulnerability	Factors affecting		
			Exposure	Sensitivity	Adaptive capacity
Federation	Biological diversity; timber and non-timber products; emission reductions; hydro-electric energy	Low for some goods and services, high for others	Geographic location; GHG emissions	Deforestation and uncontrolled logging increases sensitivity	Mobility of resources; accessibility to technology, human and financial resources; diversity of land uses; biological diversity
State government (e.g. Pará)	Biological diversity; timber and non-timber products; emission reductions	Medium to high	Geographic location; GHG emissions	Deforestation and uncontrolled logging increases sensitivity	Limited mobility; limited access to technology and resources; limited diversity of land uses
Logging companies	Timber	High	Geographic location; GHG emissions	Demand for timber; unauthorized forest conversion; forest degradation	Limited mobility and access resources; SFM and diversification of species harvested may increase adaptive capacity and reduce sensitivity
Forest communities in Pará	Timber and non-timber forest products; drinking water; soil restoration	High to very high	Geographic location; GHG emissions	High dependence on forest products and services in an area of high potential exposure	Diversity of uses; maintenance of biodiversity; very limited mobility and access to resources
Communities outside forests in Pará	Some timber and non-timber forest products; energy from wood	High to very high	Geographic location; GHG emissions	Market demand for agriculture products; poor soil management	Very limited mobility and access to resources; limited diversity

2003). For example, social, environmental and economic objectives are intricately linked and therefore adaptation and SFM decision-making must consider these multiple objectives (Burton et al. 2002, Sayer and Campbell 2004).

If SFM is to play an important role in adaptation to climate change, it will be necessary to develop, disseminate and apply a greater variety of management options, adaptable to different site conditions, considering the different thematic elements of SFM and backed-up by sound and coherent natural resource policy frameworks. These are the main focus of Chapters 6 and 7. The Expert Panel, however, recognizes that many production forests of the world, in particular in the tropics, are not managed on a sustainable basis and that there is still a long way to go to ensure good management in such forests. For this to happen, some basic conditions will need to be met, among them security of land tenure and property rights in general, availability of human and technological resources, a healthy and productive forest, and institutional frameworks (including markets) that facilitate forest management (Poore 1989, Smith et al. 2006). In addition, a broader intersectoral and participatory multistakeholder approach to forests and their management is needed to facilitate adaptation of the forest sector to changing conditions (Sabogal 2008), including those driven by climate change. New forms of governance (see Section 1.3.4 and Chapter 7) are among the main requirements to improve these enabling conditions for SFM.

Because an increasing number of forests are now being managed as elements of a landscape, SFM is becoming one of the elements of landscape or ecosystem management, taking into consideration its interactions with other land uses and users within the same geographically delimited area. Indeed, the recent trends in SFM lend themselves well to the application of the principles of the CBD's ecosystem approach (CBD 2000, Wilkie et al. 2003), although the latter usually lacks tangible objectives, concerns a geographical broader area, is cross-sectoral and puts a greater emphasis on integrating conservation and use of biodiversity (Sayer and Maginnis 2005).

1.3.4 Governance, Adaptation and Adaptive Capacity

The diverse and sometimes incompatible values held by the actors involved in decision-making around adaptation can mean that, despite the recognized IPCC definition of adaptation, the specific goals of adaptation in individual circumstances may not be consistent between actors. The values that underpin adaptation decisions become more diverse and contradictory as one moves from smaller scales and single actors to larger scales and multiple actors, as in the case of landscape or ecosystem management. This is more apparent in planned adaptation, where different actors have experienced or expect different effects of climate change on their livelihoods and therefore may have different goals. However, it also holds for autonomous adaptation, where actors may get into conflict based on the different ways they adapt to the effects of climate change.

For some actors adaptation means conservation of the status quo, while for others the current situation is undesirable and so adaptation is about progress. For example, well-developed institutions and wealthier societies or individuals may seek to maintain their current situation or standard of living through adaptation, while developing countries may aim to continue development and enhance the standard of living of their citizens. For those on the margins of society, the immediate priority may be to secure livelihoods or protect assets from climate and other risks (Rappaport 1977).

For adaptation to contribute to sustainable development, social groups of different vulnerabilities (Table 1.2) will have to agree on the appropriate decisions, their implementation and their monitoring at different levels – international, national and local. This requires a change from traditional top-down decision- and policy-making, towards multi-level information sharing, transparent decision-making, accountability, well-defined access and property rights and collaboration between the different actors or actor groups. This new type of environmental governance is discussed in more detail in Chapter 7.

1.3.5 Uncertainty and Scenarios

Providing an assessment on the current knowledge concerning forests, climate change impacts, and adaptation practices and options requires a synthesis of available information from laboratory and field experiment results, meta-analysis reviews of the scientific literature and integrated modelling analyses,. It also requires the drawing of conclusions or findings from that available information, including the authors' experience and judgment. Assessment reports such as this Expert Panel Assessment Report integrate a wide variety of information, from analytical studies to surveys to working reports. In developing a finding or determining the likelihood of an outcome, several lines of supporting evidence may exist. For quantitative analyses, expert judgment is used to assess the correctness of the underlying data, models and analyses in order to assess the chances of a finding being correct; e.g. temperature will warm. For some areas, such as adaptation practices, the literature may not yet be available to support definitive conclusions about their effectiveness. Here, authors will be drawing from associated literature and developing a conclusion based on it.

It is important to note that in an ideal world, managers would have perfect information about future climate at a particular location. This does not exist. Instead, analyses based on numerous climate and economic models suggest the changes in climate that might occur if a particular trajectory of global economic development and global mitigation strategies is adopted. With any given global climate model, each trajectory involves different future climates at particular locations based on different economic futures. Uncertainty is also introduced by the differences in the outputs of different global climate models for specific economic trajectories. As a result, while certain changes can be suggested from the unavoidable scenario group (see Chapter 3), it is impossible to project future climate changes precisely, either globally or locally. As climate change considerations are set out, uncertainties can arise on the understanding of the forest response to climate change, the completeness to which the management response of the forest is known, the extent of interactions with current stressors such as air pollution, the potential for interactions with the market and on the time span for which projections are made.

As such, there is a limit to the scientific understanding of how well adaptation options will succeed under the different groups of scenarios of climate change discussed in Chapter 3. For that reason, the Expert Panel has decided to follow the IPCC approaches in the following manner:

- When assessing literature about past observations and future potential impact and vulnerabilities associated with climate change, the following scale of confidence levels is used to express the assessed confidence of a finding being correct: very high confidence at least 9 out of 10; high confidence about 8 out of 10; medium confidence about 5 out of 10; low confidence about 2 out of 10; and very low confidence less than 1 out of 10 (IPCC 2007d).
- When assessing literature about adaptation options, uncertainty is characterized by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the extent of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III of the IPCC fourth assessment through a series of self-explanatory terms such as: high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence, etc. (IPCC 2007d).

Time is of critical importance for adaptation: it influences the level of exposure to climate change (over time effects increase) as well as our and the forests' capacity to adapt. In addition, the further in time our projections, the greater the uncertainty involved in the projections. For the purpose of this report, the Expert Panel identified the following general categories: immediate, short-term, medium-term and long-term. The perceptions regarding these timescales, however, may vary according to the main thematic areas of the report, between the different scientific disciplines involved and according to the needs of different forest user groups. The Expert Panel decided, therefore, to use absolute figures (number of years) as well, whenever possible.

1.4 Limitations of the Study

1.4.1 Other Factors Affecting Ecosystem Services

Climate change results in changes in ecosystem functions and the ecosystems' capacity to provide society with goods and services, affecting society's options for socioeconomic development. On the other hand, stakeholders' priorities define the type and quantity of goods and services used, indicating directly or indirectly which functions and biophysical attributes are most relevant for society, and therefore which ones may be under pressure and need to be managed and conserved. To serve society better in the long term, policies need to consider adaptation needs and redirect stakeholders' priorities in such a way that their use of goods and services does not affect the functions and attributes of the ecosystems to the extent that their capacity to provide the relevant goods and services is diminished.

Within this context, it is important to recognize that many factors, other than climate change, may also affect forest ecosystems' capacity to provide goods and services, including natural disturbance regimes (fires, insect and disease outbreaks, wind storms, etc.), which may also be affected by climate change and current climatic variability. In addition, stakeholders' priorities that affect the capacity of forest ecosystems to provide goods and services on a sustainable basis are and will continue to be driven by other factors than climate change and forest policies (such as markets for agricultural products, land-tenure policies, infrastructure) (Spittlehouse 2005). While the Expert Panel recognizes the need to consider these other factors in conjunction with climate change, their importance and interaction with climate change differs greatly between different natural and social systems. The Expert Panel decided, therefore, not to discuss these interactions, unless it was necessary to have a better understanding of impacts, vulnerabilities or adaptation options discussed.

1.4.2 Large-Scale Predictions Must Lead to Local Solutions

Adaptation must be local, while the reliability of projections of climate change effects decrease with scale, in particular in areas with limited data and more so for projections of rainfall rather than temperature. On the other hand, reliability for regional and local projections increases for models that allow for inclusion of more locally significant climate system processes, such as vegetation-atmosphere relations or cloud feedback (Randall et al. 2007). One of the big challenges remains, therefore, to select the right scenario and right adaptation option for a particular site.

Due to the limited time for this study and the enormous amount of information available on climate change and adaptation, it is impossible to include analyses of all possible scenarios in all forest types and under different social-economic and political settings. This report is therefore general in nature, highlighting some of the common adaptation strategies and providing examples through the use of boxed case studies. Some of these have shown that the main factor allowing for successful adaptation is local adaptive capacity through strong social and human capacities. This report will be particularly useful for those countries and project areas where these capacities exist and where the appropriate adaptation strategies can be locally selected out of the multiple options presented here.

1.4.3 Need for Action despite Lack of Information

Adaptation studies are relatively recent and while many promising experiences exist, only a few have documented evidence of their success as an adaptation strategy. This is especially true for adaptation strategies in the tropics. This assessment can provide only a picture of the experiences to date, and it is expected that similar studies five to ten years from now will give much greater insight into the effectiveness of different adaptation strategies. Climate change is progressing too fast, however, to allow for the luxury to wait and see for the results of future studies. In an assessment of climate prediction and adaptation to climate change, Dessai et al. (in press) argue that society can (and indeed must) make adaptation decisions in the absence of accurate and precise climate predictions.

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2 Forest Responses and Vulnerabilities to Recent Climate Change

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Abstract: Climate is a critical factor affecting forest ecosystems and their capacity to produce goods and services. This chapter reviews published studies of climate-forest relationships with emphasis on indications and mechanisms of change during recent decades. Effects of climate change on forests depend on ecosystem-specific factors including human activities, natural processes, and several dimensions of climate (temperature, drought, wind, etc.). Indications of recent climate-related changes in ecosystem processes are stronger in boreal forests than in other domains. In contrast, constraints on adaptive capacity that increase vulnerability to climate change are generally more severe in subtropical and tropical forests than in temperate and boreal domains. Available information is not sufficient to support a quantitative assessment of the ecological, social and economic consequences of recent forest responses to human influences on climate. The complexity of natural and human systems is a formidable barrier to impact quantification and predictability. For example, effects of land use practices and invasive species can overshadow and interact with effects of climate change. Nevertheless, substantial progress has been made in defining mechanisms of climate-change impacts on forest ecosystems. Knowledge of impact mechanisms enables identification and mitigation of some of the conditions that increase vulnerability to climate change in the forest sector.

Keywords: forests, climate, impacts, vulnerability, disturbance, complexity, adaptation, sustainable forest management, UNFCC, IPCC

■

2.1 Introduction

Many published reports have presented evidence that climate changes over the past half century have affected many aspects of forest ecosystems, including tree growth and dieback, invasive species problems, species distributions and migrations, seasonal patterns in ecosystem processes, demographics and even extinctions (IPCC 2007a). Effects of recent climate change appear to be greater in boreal forests than in other domains. In contrast, several factors that increase vulnerability to climate change appear to be more prevalent in subtropical and tropical domains than in boreal and temperate domains (Table 2.1).

Available information is not sufficient to support a quantitative assessment of the ecological, social and economic consequences of recent forest responses to human influences on climate (Backlund et al. 2008). Barriers to quantifying the impacts of anthropogenic climate change include: (a) lack of information about the nature, extent and causes of forest ecosystem change in most countries (FAO 2007); (b) uncertainty about the relative contributions of climate change and other factors to observed changes in forests (Sparks and Tryjanowski 2005); and (c) uncertainty about the relative contributions of natural and human factors to climate change and extreme weather events at the regional and sub-regional level at which ecosystem changes are usually measured (Solomon et al. 2007).

Table 2.1 Assessment of recent climate impacts and current vulnerabilities (IPCC 2007a).

Factors	Assessment
Exposure to recent climate warming	Generally higher in boreal forests
Plausible hypotheses about impact mechanisms	Plausible hypotheses have been described for all forest domains
Empirical evidence of ecosystem change consistent with impact hypotheses	Evidence stronger for boreal and temperate domains than other domains. However, this may be due in part to greater investments in research in boreal and temperate domains
Deforestation (increases vulnerability by reducing forest resilience and capacity for adaptation)	Deforestation rates generally higher in subtropical and tropical domains
Endemic forest types may have relatively high vulnerability to climate change because their limited extent may reduce resilience	Endemic forest types are more common in non-glaciated zones, including tropical and subtropical domains and warmer parts of the temperate domain
Adaptive capacity	Human dimensions of adaptive capacity in the forest sector are generally high in boreal and temperate domains; they are more variable in subtropical and tropical domains due to constraints on access to capital, information and technology

2.2 Natural History of Forest Response to Climate Change

The extent of world forests has undergone dramatic changes in response to past climate changes (Ritchie 1987). During the last ice age, which ended around 15 000 to 11 000 years ago (ice lasted longer in some areas), the world was much drier. Tropical forests were drier and fragmented. Low carbon dioxide (CO_2) levels increased physiological dryness and converted some forests to woodland (Loehle 2007). Large portions of regions now occupied by boreal forests were either under ice or occupied by tundra or cold grassland (Ritchie 1987). As the ice melted and the climate became wetter, forest expanded rapidly at all latitudes where temperatures were sufficient for tree growth.

Although rapid on a geologic timescale, the pace of forest advance in response to glacial retreat was limited by rates of seed dispersal and tree growth. In contrast, worsening conditions for tree growth and survival can cause relatively rapid retreat of the forest boundary (e.g. Tinner et al. 2008). There is, therefore, an expected hysteresis effect at forest ecotones: slow expansion of tree species boundaries as climate conditions become more favourable, and more rapid retreat in response to lethal episodes of climate-mediated stress (e.g. frost, drought) (Noble 1993).

During the current interglacial period, natural climate changes at various scales have had substantial effects on ecosystems. For example, Kröpelin et al. (2008) provide an example of a dramatic change from dry savanna to Saharan desert in response to long-term climate change over the past 6000 years, and Kobori and Glantz (1998) discuss the role that climate change has played in increasing the aridity of the Aral Sea area of central Asia. In both cases, long-term 'creeping' declines in precipitation have resulted in desertification over vast areas. Effects of climate change can be exacerbated by human activities, as in the Aral Sea basin where water use for irrigation has contributed to shrinkage of the Sea and desertification of the landscape (Kobori and Glantz 1998).

Where long-term climate changes are less extreme, the long lifespan and broad ecological tolerance of many trees means that internal forest ecotones (those between forest types rather than between forest and non-forest) are likely to respond slowly to changing climate (e.g. Loehle and LeBlanc 1996, Loehle 2003, Morris et al. 2008). For example, Eastern hemlock, a tree with poor dispersal, has been documented as still spreading north west of North America's Great Lakes in a lagged response to the end of the most recent ice age (Parshall 2002). Disequilibrium with climate has similarly been observed in forests of central Europe (Tinner and Lotter 2001).

John Innes: Sugarcane, Queensland

Photo 2.1 Conversion of forests to agriculture has been and continues to be a major cause of forest loss. For example, large areas of tropical rainforest in northern Queensland, Australia, have been converted to sugar cane (shown here).

2.3 Factors Other than Climate Affecting Forests and People

2.3.1 Introduction

Parry et al. (2007, p. 31) suggest, 'In comparison with other factors, recent warming has been of limited consequence in the agriculture and forestry sectors.' In the forest sector, important factors affecting ecosystems and people include land use and land-use change, invasive species and rapid expansion of global trade.

2.3.2 Land Use

Over the past several thousand years, land clearing for agriculture and other purposes has been a dominant force affecting the extent and condition of the world's forests. According to Bryant et al. (1997, p. 2), 'Almost half of Earth's original forest cover is gone, much of it destroyed within the past three decades.'

FAO (2007) provides estimates of recent trends in forest extent and makes the following observation about progress in slowing deforestation. 'The analysis reveals that some countries and some regions are making more progress than others. Most countries in Europe and North America have succeeded in reversing centuries of deforestation and are now showing a net increase in forest area. Most developing countries, especially those in tropical areas, continue to experience high rates of deforestation and forest degradation. The countries that face the most serious challenges in achieving sustainable forest management are, by and large, the countries with the highest rates of poverty and civil conflict.' (FAO 2007, p. v).

In some forested regions, it is possible to document changes in forest type and structure over time that are consistent with histories of human use that include major disturbances such as forest clearing, cultivation and farm abandonment leading to afforestation (e.g. Zhang et al. 2000). Urban sprawl is a relatively recent phenomenon that has created vast exurban areas in which forest ecosystems are altered in various ways (Radeloff et al. 2005). While such areas may remain forested to some extent, the land is often no longer available for traditional uses (e.g. wood production, hunting) and has characteristics such as high densities of paved roads and domestic animals that can be detrimental to many species. It can be difficult to find a 'climate impact signal' in the noise of land use history.

2.3.3 Invasive Species

In forests throughout the world, invasive species are exerting dramatic effects on all facets of ecosystem structure and function (Wilcove et al. 1998, Levine et al. 2003, Moore 2005, Asner et al. 2008). For example, invasive diseases and pests such as Chestnut blight (*Cryophonectria parasitica*) and Dutch elm disease (*Ophiostoma ulmi*) have caused major changes in the composition of forests in eastern North America over the past century (Tomback et al. 1995, Williams and Liebhold 1995, McNeely et al. 2001, Anderson et al. 2004, Logan et al. 2007, Anulewicz et al. 2008, Wingfield et al. 2008). Noteworthy invasive species affecting forests outside North America include the pine wood nematode (*Bursaphelenchus xylophilis*) in Asia and now Europe (Dwinell 1997, Naves et al. 2007) and sirex woodwasps (*Sirex noctilio* F.) in the southern hemisphere (Hurley et al. 2007).

The mechanisms for forest change in response to biological invasion vary with the system and the invasive species, but generally relate to competition with endemic species, lack of natural enemies, use of vacant niches, loss of fundamental processes such as mutualism, hybridization with genetically similar species, alteration of the physical and chemical characteristics of soils, modification of habitats, and vectors for pests and diseases (Christian 2001, McNeely et al. 2001). At the species level, direct effects of alien invasive species occur through processes such as predation, competition, and transmission of pathogens and parasites to individual organisms, eventually leading to population declines and species extinctions (CBD 2003, Loehle 2003, Chornesky et al. 2005).

The impacts of alien invasive plant species at the ecosystem level include changes to trophic structures, changes in the availability of resources such as water and nutrients, and changes in disturbance regimes (McNeely et al. 2001, CBD 2003). Systems that are rich in species are often, but not always, high in exotic species as well, possibly owing to high productivity of the system (Levine et al. 2002). In temperate forests in New Zealand, however, Ohlemuller et al. (2006) found no relationship between alien species richness and endemic species richness, suggesting that at least in those systems, climate and land use were the most important factors in invasive species success.

There are many incidences of invasive species in disturbed tropical and sub tropical systems (e.g. Richardson 1998, Moore 2005). There is evidence that natural tropical non-montane forests are less prone to invasion by alien species than disturbed forests, possibly owing to lack of available niches (Connell and Slatyer 1977).

Closed forests in general may be more resistant to invasion than forests with many canopy gaps created by disturbances (Richardson et al. 1994, Webb et al. 2000). Loehle (2003) modelled tree invasion and suggested that the more disturbance there is, the higher the probability that alien trees could invade a forest system. However, some invasions of alien species into closed forests have occurred; notably Chinese tallow (*Sapium sebiferum*) in the south-eastern USA (USDA 2000, Conway et al. 2002).

Variation in presence and abundance of invasive species in forests is not fully explained by measures of disturbance and native species diversity. This suggests that invasion depends not only on forest characteristics but also on the ecology of the invading species, including habitat preferences, food requirements, climate tolerance and presence of enemies (Mack et al. 2000, Ward and Masters 2007).

The spread of invasive species is facilitated by expansion of global trade, road networks and human presence in forests (Coffin 2007, Ding et al. 2008). Introduction of non-native trees for plantations (FAO 2007) has been an important source of invasive species in some countries (Richardson 1998, van Wilgen et al. 2001, de Wit et al. 2001, CBD 2003, Richardson and Rejmánek 2004, Moore 2005).

Alien invasive species are causing major impacts on biodiversity (Wilcove et al. 1998, Sala et al. 2000), ecosystem processes (Levine et al. 2003) and the production of ecosystem goods and services (FAO 2001, Moore 2005). Through direct impacts on species or indirectly through alterations of habitats, invasive species are responsible for placing many species at risk of extinction (Baillie et al. 2004). Loss of species as a result of alien invasive species ranks behind only habitat loss among threats to biodiversity (McNeely et al. 2001, Perrings et al. 2002, Richardson and Rejmánek 2004).

2.3.4 Global Trade in Wood Products

Production of industrial wood has risen around 1.1% per year globally since 1961, although the annual rate of growth has clearly not been constant (Figure 2.1). Output has grown the most in Latin America, southern Africa and Oceania. Growth in these regions is largely attributed to investments in new timber plantations and associated manufacturing facilities. Many of these plantations have been established with non-indigenous species, which have been found to achieve substantially higher growth rates compared to local indigenous species. Daigneault et al. (2008) estimated that non-indigenous forest plantations contribute around 13% of current global timber supply.

Rapid expansion of global trade in forest products has enhanced the economic efficiency of plantation

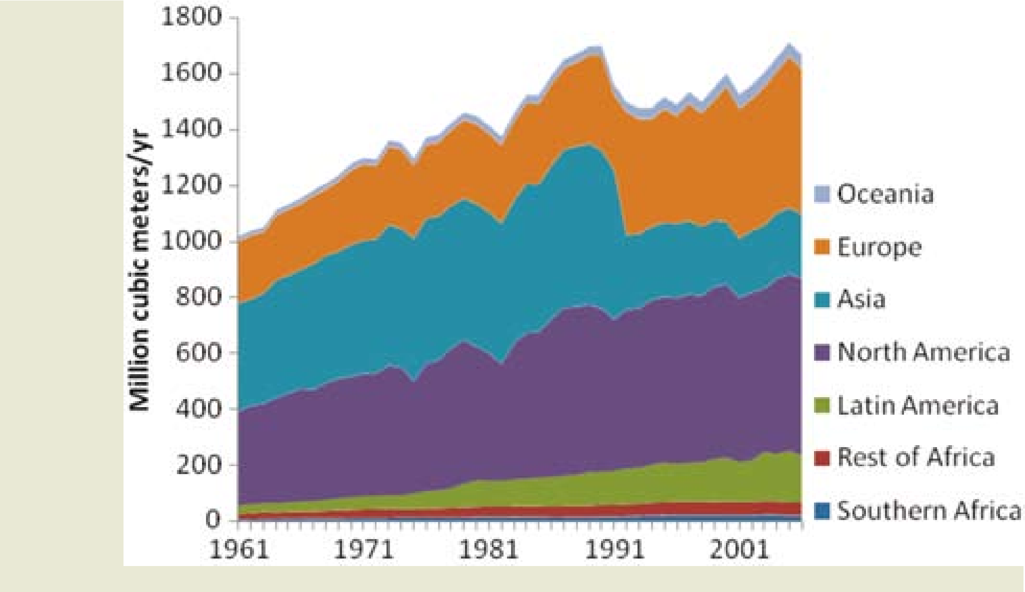

Figure 2.1 Historical wood harvest patterns by region (FAOSTAT 2008).

establishment. Between 1970 and 2001, the value of trade in forest products increased 7.5% per year (Laaksonen-Craig 2004). With increasing trade, some countries were better able to take advantage of local growing conditions and specialize in the production of fast-growing species. As a result, foreign direct investment in timber plantations and milling capacity has increased dramatically. In 1980, foreign direct investment in the forestry sectors of the USA, Canada, Brazil and Chile amounted to only about USD 2.5 billion, but by 2001, it was closer to USD 30 billion (Laaksonen-Craig 2004), implying an increase of nearly 12% per year.

Global trends towards freer capital markets, and continuing efforts to make trade freer (GATT, WTO, European Union, NAFTA, etc.) have contributed to the internationalization of the forest products industry over the past 30 years. These trends have both beneficial and adverse effects on forest ecosystem resilience and the adaptive capacity of forest managers.

2.4 Conceptual Model of Forest Ecosystem Response and Vulnerability to Recent Climate Change

Understanding recent changes in climate and forest ecosystems is a complicated task. Many drivers and dimensions of environmental change have been operating simultaneously, including atmospheric CO_2 concentrations, nitrogen deposition rates (Högberg 2007), and tropospheric ozone concentrations (Karnosky et al. 2005) as well as land use practices, invasive species and global trade. These factors have caused considerable and measurable environmental change during the industrial period (Caspersen et al. 2000, Albani et al. 2006, Hyvönen et al. 2006). Further complicating the matter are the facts that: (1) these interacting, co-occurring factors can have positive, negative or synergistic consequences for forest ecosystems; and (2) these key environmental drivers may also interact with a number of natural disturbance agents that shape forest ecosystems such as insect or disease outbreaks, or with extreme weather events and fire (Kurz et al. 2008b).

Complexity notwithstanding, substantial progress has been made in defining mechanisms of climate change impacts on forest ecosystems (Fischlin et al. 2007). In general, impacts depend on ecosystem-specific factors and their interactions. Conceptually, changes in one or more dimensions of climate (e.g. temperature and precipitation regimes) affect ecosystem processes (e.g. photosynthesis, disturbance, etc.). Alteration of ecosystem processes can lead to impacts on biodiversity and ecosystem services.

Vulnerability to climate change impacts in the forest sector depends not only on exposure to climate change and other ecosystem-specific factors but also on adaptive capacity. Easterling et al. (2007, p. 279) wrote that, 'Adaptive capacity with respect to current climate is dynamic, and influenced by changes in wealth, human capital, information and technology, material resources and infrastructure, and institutions and entitlements.'

There is substantial variation within forest domains in most factors that influence climate impacts

Erkki Oksanen: Koli, Finland

Photo 2.2 Forest ecosystem resilience is the basis for SFM, which requires an understanding of the roles of natural disturbances and long-term processes within systems. The dynamic stability over time and space allows the use of ecosystems within limits without impairment of goods and services.

and vulnerabilities (IPCC 2007a). In the boreal domain, for example, recent climate warming is spatially variable, and human adaptive capacity, while generally high, is presumably low in remote, undeveloped areas. Forests in coastal, montane and arid regions appear to have relatively high vulnerability in all domains. The vulnerability of coastal forests is related not only to sea level rise but also to exposure to strong storms and effects of human population pressures. Montane forest types occupy relatively small, disjunct areas, are subject to disturbance by human influences associated with recreation and tourism, and may have limited potential to migrate in response to climate change. Forests in arid zones occupy niches that are almost too dry to support forests and may be vulnerable to changes in the severity or frequency of droughts.

2.5 Ecosystem Resistance and Resilience to Climate Change

Biological systems maintain a certain level of resistance to environmental change. This resistance is conferred at several levels, including through genetic diversity, species redundancy, species and ecosystem adaptability, and landscape distribution. For example, Amazon forests appear to be more resistant to recent drying events than climate models would predict (Saleska et al. 2007, Malhi et al. 2008), possibly as a result of the negative effects of drying being offset by greater production owing to higher levels of CO_2 (Malhi et al. 2008). Similarly, Newberry et al. (1999) suggested that the beneficial effects of understory plants on soil moisture regimes contribute to ecosystem resistance to drought in tropical forests of Malaysia.

However, climate changes may be of sufficient magnitude to overcome resistance and force forest systems into new states or even biomes (e.g. forest to grassland). Such impacts are likely to be exacerbated and less predictable across large landscapes that lack connectivity owing to habitat loss, forest fragmentation and the inability of species to migrate. This is especially the case in tropical, subtropical and temperate forest regions where human development is most common. Therefore climate change and land-use change are closely linked, as are the consequences for biological diversity and reassembly of biological communities under climate change (e.g. Hansen et al. 2001, Noss 2001, IPCC 2002, Brncic et al. 2007).

If perturbed, forest ecosystems often recover most, if not all, of their original properties unless environmental conditions have been changed markedly. Evidence for this resilience is abundant, with forest recovery following harvesting, fire or blowdown to the same or similar states. Indeed, such resilience is the basis for sustainable forest management, which requires an understanding of the roles of natural disturbances and long-term processes within systems. This dynamic stability in time and space, even if species assemblages change, is an important component of forested systems, and for human societies, because it allows use of the systems within limits without impairment of goods and services. However, as noted above, too great a change will disable the capacity for resilience and move the forest to another state, either a different forest ecosystem, or another state entirely such as grassland or even desert.

Biodiversity is important for long-term ecosystem persistence (Drever et al. 2006) and resilient ecosystems are characterized by functional diversity at multiple scales (Peterson et al. 1998). Changes in biodiversity can occur slowly or very rapidly in response to different environmental perturbations. In managed forests, insufficient attention to biodiversity can result in loss in resilience (Levin 2000, Drever et al. 2006) and thus increase vulnerability to climate change impacts.

A predicted component of climate change is unpredictability and an increase in severe events; hence the additional stress on systems may result in unexpected change. The capacity of a system to adapt to change may depend on the past history of environmental conditions, and complex systems and forests may often cycle among several stable states (Gunderson and Holling 2002).

Fjeldsa and Lovett (1997) suggested that biological communities adapted to stability are most at risk to increasing environmental change, and noted that many areas of the tropics may thus be threatened by climate change. This hypothesis has implications for long-term planning for adaptation to climate change, such as location of protected areas, and more generally the use of goods and services under a changing climate regime in the tropics.

Tropical stability can be contrasted with boreal forest short-term instability owing to frequent perturbations by fires, wind and insects. Within bounds, these forests have been, at larger scales of time and space, highly resilient to change. Nevertheless, many authors have cautioned about the cumulative effects of multiple stressors and the possibility of major change in managed boreal systems compounded by climate effects (Gunderson and Holling 2002, Drever et al. 2006, Chapin et al. 2007).

2.6 Effects of Climate on Forest Productivity and Phenology

Many studies of forest ecosystems have correlated recent climate trends with changes in phenology (the timing of seasonal activities of animals and plants) and forest productivity (Rosenzweig et al. 2007). It appears that climate warming has lengthened the growing season and increased tree growth rates in many boreal and temperate forests. However, results of several studies suggest that warming has contributed to reductions in productivity in some forests through interactions with drought, fire and biotic disturbance (see sub-chapter 2.8).

Relationships between climate changes and forest productivity are often complicated by simultaneous changes in other factors that affect productivity, including nitrogen deposition and atmospheric CO_2 concentration (Boisvenue and Running 2006). For example, a simulation study by Beerling and Mayle (2006) attributed recent observed biomass increases on Amazon rainforest plots to anthropogenic increase in CO_2.

Changes in phenology can affect ecological relationships, e.g. by creating a mismatch between plant flowering time and presence of insect pollinators (Humphries at el. 2002, Post and Forschhammer 2007, Rosenzweig et al. 2007). Interpreting the ecological consequences of phenology changes can be challenging, as illustrated by a study that documented variation in flowering responses to warming among related cherry species and their hybrids (*Cerasus* sp. or *Prunus* sp) growing at Mt Takao in Tokyo, Japan (Miller-Rushing et al. 2007).

2.7 Effects of Climate on Biodiversity

2.7.1 Displacement of Species and Communities

Distributional changes of species toward higher latitudes and elevations have been well documented and correlated with climate warming (Rosenzweig et al. 2007). In meta-analyses, Parmesan and Yohe

(2003) and Root et al. (2003) found that over 80% of species from many studies behaved as predicted (increased, declined or moved) with climate change, across multiple systems and regions.

There is no reason to expect that climate change would displace entire ecosystems to new locations with favourable climates (Hansen et al. 2001), except possibly for the northern taiga (Chapin et al. 2004). Formation of new species assemblages is more likely (e.g. Davis and Shaw 2001, Hannah et al. 2002, Davis et al. 2005), especially where thresholds are surpassed (Chapin et al. 2004). Any reorganization of species involving the addition of key competitors, the loss of key predators or of key functional species can have large consequences for plant community assembly, and hence for the goods and services that the system is capable of delivering in the future (e.g. Schmitz et al. 2003). Interactions of climate change and higher CO_2 levels may alter species assemblages and ecosystem processes with complex and non-linear effects on forest composition (IPCC 2002, Chapin et al. 2004, Fischlin et al. 2007).

If we ask whether forests have responded to recent climate warming, it is logical to look for evidence of forest expansion where low temperatures may be limiting factors, i.e. at mountain tree lines (e.g. Holzinger et al. 2008) and at the boreal tree line (e.g. Masek 2001). Movement of mountain tree lines can be influenced by changes in firewood cutting and grazing practices (e.g. Gehrig-Fasel et al. 2007), thus complicating interpretations of climate warming effects. Filliol and Royer (2003) suggested that the taiga has been advancing into the tundra zone at a rate of 12 km/year for the past decade, but some other studies have reported much smaller rates of tree-line advance (Suarez et al. 1999, Gamache and Payette 2004, Payette 2007). The presence of krummholz (Gamache and Payette 2004) can seem to amplify the rate of forest spread in response to climate warming. Trees do not actually disappear at a sharp demarcation at tree line, but gradually become reduced in stature and more scattered. At a certain point, trees (spruce particularly) adopt a krummholz form. These trees are shrubby and only reach a height where they are protected from winter desiccation by snow cover. When the climate warms, these trees can suddenly adopt an upright growth form and small scattered trees can grow larger, giving the appearance of a rapid ecotone movement.

Non-linear relationships between climate change and ecosystem processes can produce unexpected effects on forest species composition that ultimately have implications for forest goods and services (e.g. Chapin et al. 1997). Such changes appear to be already underway in boreal forests in North America and Europe. For example in eastern North America, white-tailed deer (*Odocoileus virginianus*) are distributed about 150–200 km north of where they were found in 1970 (Thompson 2000), and moose (*Alces alces*) have moved into coastal temperate forests in western North America (Darimot et al. 2005) owing to milder winters with less deep snow. Both ungulate species are capable of altering forest species composition and growth rates of trees, depending on their densities (Thompson and Curran 1993, Niemela et al. 2001, Tripler et al. 2005). Similarly, progression of mountain pine beetles into boreal forests with a warmer climate, from their montane forest habitat, is expected to alter the relative densities of pines and spruces (Logan and Powell in press). These effects may be unexpected and yet have large consequences for forest ecosystem structure over time.

2.7.2 Risk of Extinctions with Climate Change

Biodiversity on Earth has changed during many time periods owing to altered environmental conditions (e.g. Webb 1992). For example, large numbers of species went extinct during the global warming event at the end of the Pleistocene period. Many of these extinctions were directly attributable to the change in climate (Barnosky et al. 2004, Gutherie 2006). Even in tropical zones, there were changes in communities as a result of extinctions in montane areas (Rull and Vegas-Vilarrubia 2006).

Risk of extinction is generally related to a species' extent of distribution, habitat specificity, capacities to adapt to change and disperse, metapopulation dynamics, reproductive capacity, population size and multiple human-related factors (Thompson and Angelstam 1999). Climate changes can increase extinction risk by interacting with other risk factors.

Species with small distributions and high potential for range displacement are at a very high risk of extinction as a result of climate change (Midgely et al. 2002, Schwartz et al. 2006). Narrowly distributed species that are highly limited by climatic conditions and elevation have high potential for range displacement. Extinction risk for such species is greatest if predicted future ranges are disjunct from current ranges or absent altogether, such as in the case of Australian tropical forests (e.g. Williams et al. 2003). Narrowly endemic species that are limited by non-climatic factors (e.g. soil conditions) may also be at risk of extinction under climate change. For example, interactive effects of habitat loss and drought frequency could increase extinction risk for such species. It should be noted, however, that estimates of species losses from climate change depend on a number of assumptions, and that resilience of species may be greater than assumed (Botkin et al. 2007).

Malcolm et al. (2006) suggested that hotspots were at high risk for large extinction events owing to climate change, with up to 43% of species in some cases predicted to be lost, representing 56 000 endemic plants and 3 700 endemic vertebrates. They noted that estimates of habitat loss might be reduced depending on migratory capacity, although most species would not find surrogate habitats. In terms of broad range change, other studies suggested that higher latitudes of temperate and boreal forests will be most affected (Thuiller et al. 2005, Virkkala et al. 2008) with consequent effects of habitat loss of 60% or more for many species. Thomas et al. (2004) estimated that extinctions from climate change in forested systems will range from less than 1% in northern areas to over 24% in some temperate forest zones.

Amphibians generally seem to be at high risk and provide examples of extinctions that have been linked to climate change. For example, Pounds et al. (1999, 2006) concluded that climate change and a fungal pathogen were important causes of recent extinctions of the golden toad (*Bufo periglenes*) and harlequin frog (*Atelopus varius*) in Costa Rican cloud forests. Pounds et al. (1999) suggested that climate change contributed to extinction of these species by reducing the number of days when clouds are in the forest. Other authors, however, suggest that the links between amphibian extinction and climate change are too tenuous to state conclusively (Lips et al. 2008).

Rare montane habitats without possibility of replacement at higher altitudes have seen extinctions in the past and are predicted to be at high risk in future (Rull and Vegas-Vilarrubia 2006). Finally, if the tropical areas are a cradle for evolution, owing in part to their past stability, and climate change causes species losses in these areas, especially in hotspots, then climate change has negative implications for future biodiversity at all latitudes (Jablonski et al. 2006).

There is a high degree of uncertainty surrounding consequences for forest goods and services from loss of species in forest systems. It is often not clear how species will move into vacated niches and reassemble into communities over time (e.g. Chapin et al. 2004), especially if alien species are advantaged. Further uncertainty stems from redundancy of functional roles among species, an unclear relationship between productivity and diversity, and also from the possibility of altered impacts of herbivores on plant species composition that can have unexpected effects on various goods and services, such as productivity (Chapin et al. 1997, Schmitz et al. 2003).

2.8 Effects of Climate on Disturbance in Forest Ecosystems

2.8.1 Introduction

All forests are shaped by disturbance regimes driven by climate variability in temperature, wind and moisture, which in turn affects fire, herbivory and other ecosystem processes. Forest structures, landscapes and functions at any point in time are dynamic disequilibria between maturation processes (e.g. tree growth) and disturbances at various spatial and temporal scales (e.g. Suffling 1995, Drever et al. 2006). Disturbances affect the size and age structure of trees and stands, species composition, ecosystem function and the socioeconomic value of forests. Fire, insects, pathogenes and invasive species are discussed below. In addition short term events such as storms and floods as well as large-scale circulation changes such as El Nino Southern Oscillation have effects on forest production (IPCC 2007a).

2.8.2 Fire

Climate-change influences on wildfire extent, severity and frequency depend on interactions among several factors including forest management history, drought frequency and severity, insect outbreaks and many others. There is evidence of both increase and decrease in fire activity at regional scales (Easterling et al. 2007). Forest thinning, controlled burning and other measures to reduce fuel loads and other aspects of wildfire hazard can be effective in reducing forest vulnerability to fire-mediated effects of climate change.

Effects of natural climate variation must be considered when interpreting observed changes in forest-fire regimes (Millar and Brubaker 2006). For example, a climate cycle known as the Pacific Decadal Oscillation can bring several decades of above or below average precipitation in south-western North America. During wetter periods, forest cover can expand and thicken, increasing fuel loads. Drought can then kill trees directly but can also create fires that clear large areas of trees.

Past human uses of fire should also be considered (Kay 2007). For example, intentional and accidental fires caused by humans have pushed back forest in forest-grassland ecotone regions and created parkland or savanna in others (e.g. McEwan and McCarthy 2008, Scheller et al. 2008). Conversely, human activities that exclude or suppress fire can allow encroachment of fire-intolerant species into previously fire-adapted ecosystems with adverse effects on biodiversity and risk of stand-replacing wildfires (Covington and Moore 1992).

2.8.3 Insects and Pathogens

Insects and pathogens (inclusive of native and exotic species) have major roles in forest disturbance regimes (Ayres and Lombardero 2000, Pimentel et al. 2000, Dale et al. 2001, Environment Canada 2004). Disturbance may take the form of tree mortality over large areas or scattered mortality that creates many small gaps in a forest.

Forest resistance to disturbance by insects and pathogens depends on many factors including tree species, stand ages and vigour, and climate. In some cases, investments in planted forests are impaired by damage from pests that are not significant problems in natural forests (Mack et al. 2000, Cock 2003, Wainhouse 2005). Reductions in tree diversity and high local densities of host trees seem generally to promote outbreaks of plant pests and pathogens (Jactel et al. 2005, Moreau et al. 2006). However, opportunities for early detection and effective management of pestilence are often greater in plantations. Where plantations are established using non-indigenous tree species, losses to pestilence can be low if the trees' native pests and pathogens are absent. This advantage can be reversed when invasions by native enemies occurs, and then the pestilence can be severe because pests and pathogens frequently have no enemies of their own in the new environment (Elton 2000, Lombardero et al. 2008).

Changes in climate can influence forest pestilence via relatively direct physiological effects on herbivores and pathogens, via effects on tree defences against herbivores and pathogens, and/or via effects on predators, competitors and mutualists of herbivores and pathogens. Forest pestilence can also produce feedback to the atmosphere by influencing fluxes of CO_2 (Kurz et al. 2008a) and probably water.

An emerging generalization is that inducible defences of plants tend to be positively correlated with environmental conditions that favour plant growth (e.g. increased precipitation leads to increased plant growth and increased efficacy of inducible plant defences), while constitutive defences tend to become less when water and/or nutrient availability increases (Lombardero et al. 2000a, Hale et al. 2005). This dichotomy may explain the frequent but variable effects of plant 'stress' on herbivore populations (Koricheva et al. 1998).

Interactions between forest pestilence and fire can be a primary determinant of ecosystem structure and function (Baker and Veblen 1990, van Mantgem et al. 2004, Parker et al. 2006). In some cases, the interactions produce a destabilizing positive feedback system. For example, fires can promote outbreaks of pests and pathogens (Thomas and Agee 1986, McCullough et al. 1998), and pests and pathogens can increase the probability of fires (Wood 1982, Raffa and Berryman 1987). In other situations, fires can reduce pest outbreaks (Hadley and Veblen 1993, Kipfmueller and Baker 1998, Holzmueller et al. 2008), and fire suppression can promote the development of large expanses of even-aged forests that have a high risk of epidemics from pests and pathogens (Meentemeyer et al. 2008, Raffa et al. 2008).

Several lines of evidence and argument support the hypothesis that recent changes in climate and other environmental factors have affected forest vulnerability to pestilence:

- The physiology of insects and fungi is highly sensitive to temperature, with metabolic rate, and therefore resource consumption, tending to about double with an increase of 10 °C (Gillooly et al. 2001, Clark and Fraser 2004). There is evidence that warmer is generally better for insects, even in climates that are already warm (Currano et al. 2008, Frazier et al. 2006). However, pestilence may tend to decrease in the warmer edges of contemporary distributions, as predicted by the model of climatic envelopes (Williams and Liebhold 1995). This model may help explain why the southern pine beetle has recently become less common in the pine forests of Texas and Louisiana even though it has been of great importance historically (Clarke et al. 2000, Friedenberg et al. 2008).
- The timing of life history stages (phenology) of many insect species has already been demonstrably advanced by warming temperatures (Harrington et al. 2001, van Asch and Visser 2007), and there are examples of insect distributions extending northward (Parmesan 2006). There are also reports of growing damage from some forest pests at the poleward and/or alpine limits of their historical occurrences (e.g. Jepsen et al. 2008, Lima et al. 2008).
- Climatic warming may generally reduce the risk to herbivore and pathogen populations of winter mortality (Bale et al. 2002, Battisti et al. 2005, Régnière and Bentz 2007, Tran et al. 2007). However, some insects that overwinter in forest litter may face higher mortality rates due to decreased snow depth (Lombardero et al. 2000b).
- Climate change may affect the frequency and intensity of extreme climatic events (IPCC 2007a). These events, such as ice storms and wind damage, may result in widespread disturbance in forest ecosystems, providing increased opportunities for invasive species to attack vulnerable trees and become established in disturbed areas (McNeely et al. 2001). Mechanical damage of plant tissue from storms can enable infection by pathogens (Shigo 1964).
- Increases in precipitation favour many forest pathogens by enhancing sporulation, dispersal and

host infection (Garrett et al. 2006). Drought stress can increase or decrease tree defences against herbivores and pathogens (Mattson and Haack 1987, Lombardero et al. 2000a, Hale et al. 2005).

- Climate can affect concentrations of secondary metabolites and nutrients in plant tissues, with consequences for herbivores (Herms and Mattson 1992, Landsberg and Smith 1992, Bidart-Bouzat and Imeh-Nathaniel 2008). Moreover, climate can affect natural enemies of insect pests (Burnett 1949) and ecologically important symbionts (Lombardero et al. 2003, Six and Bentz 2007).
- Anthropogenic increases in nitrogen deposition and atmospheric concentrations of CO_2 and ozone can impact forest disturbance by insects and pathogens (Meadows and Hodges 1996, Karnosky et al. 2005, Burdon et al. 2006, Zvereva and Kozlov 2006). The suitability of plant tissue for herbivores tends to be decreased by increases in CO_2 (Stiling and Cornelissen 2007) and increased by nitrogen deposition (Throop and Lerdau 2004).
- Forest fragmentation can affect resistance to biological disturbance, but the effect can be to increase or decrease pestilence depending on the system (Roland 1993, Holdenreider et al. 2004, Ylioja et al. 2005).

Warm climate conditions have clearly contributed to some recent insect epidemics: e.g. bark beetles in North America (Berg et al. 2006, Tran et al. 2007, Raffa et al. 2008), defoliators in Scandinavia (Jepsen et al. 2008), aphids in the United Kingdom (Lima et al. 2008) and the processionary moth in continental Europe (Battisti et al. 2005, 2006). Some modelling studies suggest that many boreal forests are vulnerable to increases in tree mortality leading to an increased frequency of stand-replacing fires, exacerbated by a warming climate (e.g. Johnston et al. 2001, Kurz et al. 2008b). In temperate and tropical ecosystems, where gap dynamics are more important than in the boreal zone, the effects of warming on gap disturbances from invasive species are uncertain except that there will likely be shifts in forest species composition (Hunt et al. 2006, Brown et al. 2008).

Recent impacts of the native mountain pine beetle (MPB) (*Dendroctonus ponderosae*) in western North America are noteworthy for their scale, economic significance and apparent links to climate. The MPB had produced extensive mortality throughout 13.5 million hectares of lodgepole pine (*Pinus contorta*) by 2008, including in areas further north, east and at higher elevations than previously recorded (Aukema et al. 2006, Logan and Powell in press). This epidemic was facilitated by recent climatic patterns (mild winters and warm dry summers; Logan and Powell 2001, Carroll et al. 2004, Régnière and Bentz 2007) in combination with fire suppression during the last century that created extensive tracts of mature susceptible pine stands (Raffa et al. 2008).

It appears that warm climate conditions have transformed MPB into an invasive native insect based on: (1) intensified outbreaks within historical range; (2) range expansion to the north; (3) range expansion into endangered high elevation forests of whitebark pine (*P. albicaulis*); and (4) expansion into forests of jack pine (*P. banksiana*), which creates the potential for massive range expansions into north central and eastern North America (Logan et al. 2003, Logan and Powell in press). Moreover, the MPB epidemic has been progressing as predicted by Logan and Powell (2001) based upon models of climatic effects on beetle physiology. These models project an eventual northern range expansion of 7° latitude (780 km) under a warming scenario of 2.5°C.

2.8.4 Invasive Plants

Climate change can affect forests by altering environmental conditions and increasing niche availability for invaders (McNeely 1999, McNeely et al. 2001, Hunt et al. 2006, Ward and Masters 2007, Dukes et al. in press, Logan and Powell in press). Ecosystem susceptibility to invasion by alien plant species has been linked to species richness, ecosystem disturbance and to the functionality of species (Mack et al. 2000). Disturbance and loss of native species can open niches and reduce competition to invading species (Kennedy et al. 2002).

Rouget et al. (2002) noted that the current distribution of stands of invasive trees in South Africa was largely influenced by climatic factors. Climate change can facilitate the spread of invasive plant species by accelerating disturbance rates and contributing to the loss of native species while increasing the range and competitiveness of invasive plants (Schnitzler et al. 2007).

The complex interactions of climate change and invasive species make effects at the community level especially difficult to predict (Williams et al. 2000, Moore 2005). After climate change, dominant endemic species may no longer be adapted to the changed environmental conditions of their habitat, affording the opportunity for introduced species to invade, and to alter successional patterns, ecosystem function and resource distribution (McNeely 1999, Tilman and Lehman 2001).

James Miller: United States

Photo 2.3 Invasive species are among the most globally significant factors affecting forest ecosystems and biodiversity. Kudzu (shown here) invaded many forests in the southern United States after it was imported from Japan to reduce soil erosion. Controlling invasive species and other stress factors can reduce forest vulnerability to some aspects of climate change.

2.9 Insights from Experiments

2.9.1 Introduction

Controlled experiments are among our most important tools for measuring the separate and interactive effects on forests of climate change and air pollution. They provide exposure-response science support for interpretation of field observations and monitoring data. They also provide critical inputs for modelling impact mechanisms and future impacts of climate change.

2.9.2 Elevated CO_2 Experiments

Atmospheric CO_2 has risen some 33% since the pre-industrial period but remains well below the point of CO_2 saturation for photosynthesis in most tree species. There is considerable interest in the hypothesis that past and ongoing increases in atmospheric CO_2 are causing increases in forest productivity.

Across a host of experiments, increases in photosynthetic levels have averaged 40% in response to simulated increases in CO_2 from pre-industrial levels to 500 ppm, a concentration predicted for the middle of this century (Ellsworth et al. 2004, Ainsworth and Long 2005). For young temperate-zone forest stands exposed for nearly a decade to elevated CO_2 using Free-Air CO_2 Enrichment (FACE) technology, the increase in forest productivity has averaged 23% across a range of tree species tested on two continents (Norby et al. 2005). Relative growth enhancement varied by species (Karnosky et al. 2005), genotype (McDonald et al. 2002) and from year-to-year depending on climatic conditions (Kubiske et al. 2006, Moore et al. 2006). This increase in productivity is driven largely by the enhancement of photosynthesis, but it is also affected in some, but not all, species by increased leaf area (Karnosky et al. 2005), extended growing season (Taylor et al. 2008) and increased root growth, allowing for increased soil volume exploitation for available nutrients and moisture (Norby et al. 2004, King et al. 2005).

Increased water use efficiency can also contribute to productivity enhancement, particularly under water-limiting situations because elevated CO_2 causes a reduction in stomatal conductance (Medlyn et al. 2001). However, elevated CO_2 concentrations can also alter physical/chemical leaf defences against insects, leading to changes in leaf quality that result in changes in herbivory (Percy et al. 2002, Karnosky et al. 2003, Kopper and Lindroth 2003). Effects of elevated CO_2 or ozone (O_3) on insect performance as mediated through natural enemy populations may be more difficult to predict (Awmack et al. 2004).

Only a few studies of CO_2 enrichment effects have been completed on older trees. These trees have tended to be less responsive to elevated CO_2 than younger trees (Körner et al. 2005, Asshoff et al. 2006). However, because of the size of the trees involved, such studies have not been as statistically robust as have the younger tree studies.

2.9.3 Warming Experiments

Historical records show an increase in mean global temperature of 0.6°C over the last 100 years (IPCC 2007b). Essentially all chemical and biological processes are affected by changes in temperature (Saxe et al. 2001), so it is axiomatic that warming has already had many effects on forest ecosystems. However, effects of warming in forests are confounded with effects of co-occurring increases in CO_2, land-use change and other factors such as drought and fires. Controlled experiments are useful in understanding effects of warming alone and in combination with other factors.

Scientists have conducted a vast array of diverse warming studies of trees and forests using growth chambers, mesocosms, open-top and closed-top field chambers, common garden studies across temperature gradients, and heated open-air plots. In addition, a number of soil-warming studies have been conducted using various methods: e.g. removing winter snow to create differences in spring soil warm up; placing passive covers over lower-statured vegetation to reduce night-time heat loss to the atmosphere; and heating the soil with electric cables buried in upper soil layers. Most warming experiments are restricted in their temporal scope – e.g. daytime only, night-time-only or seasonal – for budgetary and other practical reasons.

Interpretation of the warming experiment literature is constrained by the fact that investigators have used so many different experimental designs and methods. Nevertheless, some consensus from warming experiments is emerging as to how warming will impact forest ecosystems. Warmer temperatures at northern latitudes will likely enhance photosynthesis and growth through increases in maximal summer photosynthesis, and by increases in the seasonal duration of photosynthetic activity (Saxe et al. 2001, Norby et al. 2003, Danby and Hik 2007, Peñuelas et al. 2007, Slaney et al. 2007, Bronson et al. 2008, Post et al. 2008). Tropical forests remain largely unstudied from the standpoint of warming experiments (Fearnside 2004, Feeley et al. 2007). This remains an important research need as the tropical forests play a key role globally as carbon sinks, and recent studies have suggested this sink may be adversely impacted by climate change (Fearnside 2004, Feeley et al. 2007).

A second topic of major concern regarding global temperature increases is the potential for major shifts of tree species toward the poles, and upwards on mountain slopes (see sub-chapter 2.6). Some models indicate forest vulnerability to regional-scale dieback (Houghton 1996) and major changes in species ranges (Iverson and Prasad 2001, Parmesan and Yohe 2003). Other studies have raised questions about the validity of these models (Loehle 1996, Loehle and LeBlanc 1996). Warming experiments and associated modelling efforts provide useful insight into this scientific discussion as they have clearly demonstrated that there is large plasticity in response for many of the tree species examined (Rehfeldt 1988, 1989, King et al. 1999, Gunter et al. 2000, Rehfeldt et al. 2004, Reich and Oleksyn 2008). This growing body of research suggests that vegetation models designed to predict species' responses to global warming need improvement with respect to their capacity to evaluate the extent and structure of genetic variation.

Less scientific consensus has developed around forest vulnerability to impacts of warming on soil organic matter decomposition and on soil carbon accumulation and release (Davidson and Jansens 2006, Bronson et al. 2008). This is an important research question because models of temperature effects on soil organic matter decomposition derived from laboratory studies predict large decreases in global soil organic matter as a result of warming alone (e.g. 8–12 Pg C $°C^{-1}$) (Saxe et al. 2001). While some studies have found that warming significantly increases CO_2 efflux (Rustad and Fernandez 1998) from soils, others have shown substantially less CO_2 efflux than has been predicted by models (Niinisto et al. 2004, Bronson et al. 2008). Soil organic matter decomposition and CO_2 efflux from soils will likely be altered under global warming but the amounts will probably not be as great as lab-based models predict (Davidson and Janssens 2006).

2.9.4 Altered Precipitation Experiments

A key global change driver closely associated with warming is drought. Water availability affects almost all processes underlying forest tree growth and reproduction. Water stress due to drought is a key factor affecting limits of distribution of tree species. Even one or two seasonal droughts can trigger a cascade of events leading to dieback, decline or increased risk of fire (Jones et al. 1993, Hanson and Weltzin 2000, Asner et al. 2004, Nepstad et al. 2004, Breshears et al. 2005) or major pest outbreaks (Rouault et al. 2006, Dobbertin et al. 2007, Kurz et al. 2008a). Global change models suggest that there will be changes in drought occurrence and impacts in many areas of the world over the next century. Thus, water manipulation experiments can play a key role in evaluating model assumptions and results.

Throughfall exclusion experiments that alter rainfall amounts reaching the soil surface by 30–50% have been conducted in temperate oak forest in Tennessee (Wullschleger et al. 1998) and in the Brazilian tropics (Nepstad et al. 2002, Fisher et al. 2006). These studies have documented decreases in whole-plant water flux in response to simulated reductions in rainfall (Wullschleger et al. 1998, Romero-Saltos et al. 2005, Fisher et al. 2007, 2008). Few other responses to simulated changes in rainfall were detected in the temperate oak forest, despite intensive monitoring of growth, leaf area development, leaf duration and leaf senescence (Hanson et al. 2001, Wullschleger and Hanson 2006). In contrast, similar precipitation manipulations in the Brazilian tropics affected reproductive phenology, litterfall, wood production, below-ground carbon cycling and large-tree mortality (Brando et al. 2006, Nepstad et al. 2007, Brando et al. 2008).

There is no clear consensus yet as to long-term effects of droughts on soil CO_2 flux (Sotta et al. 2007). Interaction of deforestation and increased frequency of drought due to land-use change and climate change are predicted to also alter soil carbon efflux in the tropics (Nepstad et al. 2008). However, results from two major precipitation exclusion studies have shown mixed results in terms of soil CO_2 efflux. While a small increase (9%) in soil CO_2 efflux was measured over three years at the study in Santarén, Brazil (Fisher et al. 2007), there was a drought-induced decrease in soil CO_2 efflux in the Caxiuanã, Brazil study (Sotta et al. 2007). The authors speculated that different soil types and available soil moisture were likely to have caused these differences (Sotta et al. 2007).

As with responses reported for other global change drivers, there is a large genetic variation in response to drought (Ogaya and Peñuelas 2007, Slot and Poorter 2007, Meier and Leuschner 2008). It is clear that mechanisms of genetic control of drought tolerance are only beginning to be elucidated (Street et al. 2006).

2.9.5 Flux Tower Experiments

Ecosystem-level CO_2 exchanges between terrestrial ecosystems and the atmosphere are being monitored using eddy-covariance techniques from a network of over 500 tower sites worldwide. Monitoring data from these towers has improved understanding of the effects of extreme events that may occur with increasing frequency under climate change. For example, the gross primary productivity over Europe was reduced some 30% during the heat wave and drought of 2003 (Ciais et al. 2005, Peñuelas et al. 2007). Similar reductions in net ecosystem carbon exchange were detected for Portuguese forests during the severe drought experienced in 2004–2005 (Pereira et al. 2007).

Boreal forest ecosystems, which are large reservoirs of soil-held carbon, are particularly vulnerable to carbon release under global warming (Goulden et al. 1998). Recently, flux measurements have been useful in showing that the carbon balance of these northern ecosystems has been shifted to one of higher respiration, particularly in the autumn as these regions have warmed over the past two decades. Results indicate vulnerability to reductions in the capacity of northern ecosystems to sequester carbon as global warming continues (Piao et al. 2008).

2.9.6 Phenological Gardens

Phenological shifts (particularly bud break and flowering dates) have emerged as a prime indicator of forest responses to global warming in temperate and boreal forests (Menzel and Fabian 1999, Walther et al. 2002, Sherry et al. 2007). Important data sources include phenological gardens where investigators have monitored dates of spring bud break, flowering and autumnal foliar coloration (Menzel and Fabian 1999). Repetitive examination of keystone species in these gardens has documented advancements in dates of spring bud break ranging from 2.3 to 5.1 days per decade (Menzel and Fabian 1999, Chmielewski and Rötzer 2001, Wolfe et al. 2005, Menzel et al. 2006, Pudas et al. 2008). However, there is some evidence that part of this phenological change may be due to increasing atmospheric CO_2 concentrations as well as warming (Taylor et al. 2008).

Reported changes in phenology are generally greatest at higher latitudes and have been correlated with rising temperatures over the past several decades (Parmesan 2007). Interestingly, results from phenological gardens have correlated very well with satellite imagery used to follow seasonal green-up and with measurements of the variations in the timing and amplitude of the seasonal cycle of atmospheric CO_2 (Linderholm 2006), showing the value of phenological gardens in 'ground truthing' a key climate-change phenomenon. In the tropics, tree phenology is driven largely by seasonal water availability, so leaf out and leaf longevity are not useful indicators of climate warming (Borchert et al. 2005).

2.9.7 Research Needs

Experiments have provided important insights into the potential effects on forests of climate change variables and interacting factors. For example:

- Recent CO_2 increases and climate warming are consistent with (and may be contributing to) observed increases in forest productivity in some regions (Norby et al. 2005). Any increase in carbon sequestration due to elevated CO_2 occurs largely from enhanced tree growth, as increased soil respiration under elevated CO_2 results in little added soil carbon build-up (King et al. 2004).
- Effects of CO_2 on tree growth can be diminished by co-occurring effects of factors such as nutrient limitations (Oren et al. 2001), pest activity

or elevated tropospheric ozone (Karnosky et al. 2005). However, elevated CO_2 can mitigate impacts of drought on forests by increasing water use efficiency (Medlyn et al. 2001).

- Community structure can be altered by elevated CO_2 as different species and communities are favoured under elevated CO_2 compared to control conditions, both above ground (McDonald et al. 2002, Kubiske et al. 2007, Mohan et al. 2007) and below ground (Phillips et al. 2002, Zak et al. 2007).

It should be noted, however, that the vast majority of global change experiments have been conducted as single-factor studies with young temperate-zone trees. There is a need for more multiple-factor studies of the key climate-change drivers with tree species from boreal, subtropical and tropical domains (Karnosky et al. 2003, Hyvonen et al. 2006). These studies must be well-replicated, robustly designed, and run for the long term to allow for exposure under a range of local climatic conditions for stand dynamics and pest population cycles to operate so that the important role of global change drivers in predisposing trees to other biotic and abiotic stressors is better understood (Percy et al. 2002).

Very little experimental work with elevated CO_2, warming or drought has been done on mature trees, so this remains a large knowledge gap that hinders modelling of future impacts of climate change on forest productivity. Similarly, almost no experimental work has been done with warming or elevated CO_2 in tropical forests. Model predictions are that greater CO_2 enhancement will occur in tropical trees than has occurred in temperate forest trees (Hickler et al. 2008), but that warming effects on respiration will largely offset these positive effects (Lloyd and Farquhar 2008).

The interactions of climate-change drivers with nutrient dynamics and important air pollutants have not yet been adequately studied. The current theory of ‘progressive nutrient limitation’ suggests that long-term responses to elevated CO_2 will lower nitrogen availability (Oren et al. 2001) and thereby limit subsequent growth responses. This highly contentious theory has not been validated, particularly on relatively fertile sites (Finzi et al. 2007). Similarly, the role of tropospheric O_3 in limiting the sink strength of forest trees remains poorly understood (Reilly et al. 2007, Sitch et al. 2007) and is tightly linked to climate change (Vautard and Hausglustaine 2007). Elevated concentrations of tropospheric O_3 are predicted to affect large areas of the world’s forests in this century (Felzer et al. 2007).

2.10 Conclusions

The complexity of natural and human systems is a formidable barrier to quantification of climate change impacts in the forest sector. 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.). Changes in climate can influence forests simultaneously in opposing directions. For example, warming of mid- to high-latitude forests tends to increase productivity in the absence of disturbance, but also tends to increase forest disturbance. It is also necessary to consider cumulative effects and interactions of climate changes, forest management, air quality, invasive species and other factors.

Complexity often stymies quantification and predictability of climate change impacts, but also provides many different pathways to adaptation when local or scientific knowledge is sufficient to define the dimensions of climate change and their interactions with natural and human systems. It is known already that warming can influence the geographic range and behaviours of herbivore species, thereby altering plant community structures and disturbance regimes in forest ecosystems. Such knowledge of herbivore biology, ecology and management can inform the development of adaptive responses to climate change. For example, theory and experience support the general concept that thinning of overstocked stands can reduce climate impacts on forest productivity mediated by insects that feed on trees.

The resilience of forest ecosystems supports human adaptation but can be overcome by severe disturbance and sufficiently large changes in climate. Trees can die rapidly and en masse, but forest regeneration and regrowth are relatively slow processes. Therefore, small changes in disturbance regimes can have large, lasting effects on forest ecosystems. Sometimes, disturbance-related changes in forests are made more difficult to reverse by associated alterations in, for example, soils, seed sources, pollinators, seed dispersers, herbivores and local climates. Because of the relatively long time required for natural forest regeneration following disturbance, there can be advantages to proactive changes in management compared to reactive changes.

Proactive adaptation measures based on knowledge of climate impact mechanisms have potential to prevent reductions in ecosystem goods and services in forests managed actively for timber and non-timber forest products. Effective adaptation requires explicit recognition that climate is one of many drivers of ecosystem change (Vitousek 1997, Chapin et al. 2000, Hanson et al. 2001, Chambers et al. 2007, Chapin et al. 2008). Non-climatic factors can influence forest disturbance regimes via interactions with climatic effects. Such interaction can take the form of feedback systems that tend either to stabilize or destabilize forest ecosystems (Ayres and Lombardero 2000, Bonan 2008). Recognizing and managing these feedback systems offers a general pathway to adaptation of human interactions with forests subject to climate change.

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3 Future Environmental Impacts and Vulnerabilities

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Abstract: The focus of this chapter is on climate-change impacts on the environment, the structure and functioning of forests, on their biodiversity, and on the services and goods provided by forests in order to identify key vulnerabilities. Based on the findings of the IPCC Fourth Assessment Report (IPCC 2007d), we first introduce four clusters (*unavoidable*, *stable*, *growth*, and *fast growth*) of climate change scenarios commonly used to quantitatively assess climate change impacts (sub-chapter 3.2). At the global scale (sub-chapter 3.3) as well as in the four domains (boreal – sub-chapter 3.4; temperate – 3.5; subtropical – 3.6; tropical – 3.7), our CCIAV-assessment (see glossary) for forests shows that many forests can adapt to a moderate climate change if water is sufficiently available, notably in currently temperature limited areas (*unavoidable*, lower end *stable*). In some temperate or boreal regions, certain forests can even increase their primary productivity in a moderate climate change. However, some of these benefits are easily offset as climate warms and the adaptive capacity of currently water limited, fire or insect prone forests is frequently exceeded already by a limited climate change (*unavoidable*, *stable*). Many other forests become also vulnerable to an unmitigated climate change (*growth*, *fast growth*) as their adaptive capacity is exceeded. Forests currently sequester significant amounts of carbon; a key vulnerability consists in the loss of this service, and forests may even turn into a net source. Among land ecosystems, forests currently house the largest fraction of biodiversity; unmitigated climate change threatens to put significant parts of it at risk. The boreal domain, being especially sensitive, serves as a model case and is treated in particular depth. Finally, conclusions are drawn to summarize all findings on the global as well as regional scales (sub-chapter 3.8).

Keywords: Climate change scenarios, climate change impacts, forest properties, forest functioning, forest services, climate triggered disturbances, autonomous adaptation, climate change opportunities, adaptive capacity, forest resilience, key vulnerabilities

■

3.1 Introduction

Forests provide many ecosystem services that are key to human well-being (cf. Chapter 1). This chapter focuses on impacts of climate change on these services, and elucidates how different scenarios of climate change can and will affect forests and their services, mostly only indirectly through a multitude of interdependent processes in a complex manner.

Many forest services have not yet been recognized as having value by markets (for a recent review on these issues cf. Fischlin et al. 2007, sub-chapter 4.5). Yet other approaches such as the recurrent themes (cf. Chapter 1) allow for the roles of forests to be described within a more market-oriented context. For a Climate Change Impacts, Adaptation, and Vulnerability (CCIAV) Assessment we need to know how forests will be exposed to climate change, how sensitive they are to that exposure, and in how far they have the capacity to adapt. Future exposure and sensitivity (cf. Chapter 2) determine future impacts and are typically given in a climate change scenario as simulated by a climate model forced by an emission scenario attempting to capture future human behaviour (cf. sub-chapter 3.2). Any response by a forest ecosystem – either at the scale of leaves, branches, trees, stands or up to the scale of entire biomes – can be modelled by an impact model and is understood as autonomous adaptation (cf. Chapter 2), since that response by the forest is not directed at avoiding or minimizing adverse impacts (cf. Chapter 4). This is in contrast to human adaptation, typically attempting at avoiding adverse impacts or exploiting beneficial opportunities, e.g. through silviculture (cf. Chapter 5) or through policy measures (cf. Chapter 7). When the adaptive capacity is sufficient to counteract the impacts from climate change, the forest ecosystem may continue to behave in a mode similar to the past. Otherwise, when the forest system's resilience breaks down and causes the ecosystem to switch to an entirely new mode of behaviour, for instance when a forest becomes grassland, such a forest is considered to be vulnerable to climate change.

Given that forests cover about a third of the Earth's land in many climates, store about half of all carbon (Fischlin et al. 2007), and very likely house the majority of biodiversity of land ecosystems, in accordance with the precautionary principle (cf. Chapter 1, 7), impacts of future climate change on forest properties, structures, goods, and services are of major interest to humankind (cf. Chapter 7). Moreover, since forests may not only be impacted by climate change, but play also a major role in the global carbon cycle, their fate is of decisive relevance also for the future fate of the climate system. Unfortunately, current approaches and models do not yet allow studying this interplay between forests and the rest of the climate system in a fully coupled manner. Nevertheless, impacts and possible feedbacks can be assessed systematically, enabling us to address the risks of climate change in an appropriate framework.

3.2 Climate-Change Scenarios

Any CCIAV assessment (see glossary) is based on particular, assumed environmental and socio-economic conditions and requires scenarios of climate change that are internally as consistent as possible and portray plausible representations of the future. Currently a large number of climate change scenarios are used for CCIAV assessment scenarios that are based on various assumptions about basically unknown future socio-economic conditions and their associated anthropogenic emissions that are used to create climate models. For the sake of simplicity, future climate change scenarios are grouped into four scenario clusters, thereby reducing the number of options for discussion of climate change impacts in the context of this report: *unavoidable*, *stable*, *growth* and *fast growth*. These categories relate mostly to current carbon dioxide (CO_2) emission paths and should be of particular relevance in the current climate change debate as it relates to impacts on forests. However, other clusters could have been chosen. This sub-chapter briefly introduces and describes some of the scenarios most often used in the context of CCIAV studies on forest ecosystems at the global as well as the regional scale, in particular as they pertain to the case studies discussed in this report.

Future climate change depends on many uncertain factors. There is still much debate not only about the causes of climate change and climate sensitivity (see glossary), but also the likely impact of future anthropogenic emissions of greenhouse gases, aerosols, the cycling of key elements like carbon and nitrogen, land-use change and various land-use or land management related effects. Despite these uncertainties, projections of future climate change are needed to address the potential human influence on climate and to decide on mitigation and adaptation measures.

Climate change projections are based on plausible, quantitatively specified assumptions about the possible evolution of demographic, socio-economic, technological and environmental factors. They all affect human emissions of greenhouse gases (GHGs) and aerosols and, thus, impact the Earth's radiation balance and ultimately climate. For example, future growth of human population, together with technological advances, will determine to some extent the usage of fossil fuels and associated greenhouse gas emissions. Some of these factors are also impacted by a changing climate, e.g. carbon sequestration by forests, or technology use dependent on infrastructures (Wilbanks et al. 2007). Thus, feedbacks emerge, which complicates the situation.

Moreover, the climate system's response to external forcings needs to be studied at the proper time scales. This is particularly important in the context of forests, since they respond more slowly than many other ecosystems and need to consider fast processes such as photosynthesis responding within seconds, as well as slow ones such as forest succession lasting centuries. Therefore, response times of forests are comparable to those of the climate as they respond to changes in radiative forcing (see glossary) resulting from changes in the chemical composition of the atmosphere. In the case of forest succession or soil formation response times are similar to the slowest components of the climate system such as the oceans, which operate at time scales of centuries to millennia. Century-long time scales contrast sharply with some human decision-making. This creates particular challenges for the consistency of scenarios, especially when projected far into the future. Consequently, socio-economically based emission scenarios cover typically only the 21st century. A few scenarios extend beyond 2100 to study the longer-term response of the climate system. Those scenarios are, of course, particularly welcome if we wish to study impacts of climate change on forest ecosystems.

3.2.1 Commonly Used Scenarios

The majority of emission scenarios and concentration pathways for all relevant GHGs and aerosols as used in current CCIAV assessments have been developed in the context of the Intergovernmental Panel on Climate Change (IPCC) reports in the course of the last two decades. Among those, the most commonly used are CO_2-only stabilization pathways (Wigley et al. 1996, Plattner et al. 2008) and multigas emission scenarios from the Special Report on Emission Scenarios (SRES) of IPCC (Nakicenovic et al. 2000). Some impact studies still use the older, simpler business-as-usual scenarios (IS90, IS92a, IPCC, 1990, 1992) as well as $2xCO_2$ scenarios, but the majority now uses the IPCC SRES scenarios. There are also new successor scenarios modifying or extending IPCC SRES scenarios such as constant radiative forcing after 2100, or zero emissions after 2000 (e.g. CMIP – Meehl et al. 2007) or 2100 (Plattner et al. 2008).

The CO_2-only stabilization profiles usually prescribe the pathway of the atmospheric CO_2 concentration following projections based on a particular emission scenario (Meehl et al. 2007, Plattner et al. 2008) up to a certain point in time and then allow the CO_2 concentration to stabilize at a given level. The SRES emission scenarios on the other hand are based on a set of storylines representing different demographic, social, economic, technological and environmental developments. The 40 IPCC SRES scenarios have been grouped into four scenario 'families' characterized by common narratives. Six scenarios are the most often used: A1B, A1FI, A1T, A2, B1 and B2.

The A1 family describes a future with a relatively low population growth but rapid economic growth and high energy and material demands moderated by rapid technological change. The A1 scenario family develops into three groups that describe alternative directions of technology change in the energy system. The A1FI scenario is representative of a fossil-intensive energy sector. Non-fossil energy sources are emphasized in the A1T scenario, whereas non-fossil energy sources and fossil sources are 'balanced' in the A1B scenario. The A2 family describes a heterogeneous world with economic development regionally oriented, slower economic growth and relatively high population growth. The B1 family describes a convergent world with low population growth as in A1 but with rapid changes in economic structure toward a service and information economy and the introduction of clean technologies. The B2 family describes a world in which the emphasis is on local solutions, with moderate population growth, intermediate levels of economic development, and less rapid technological change than in A1 or B1. Further details on the SRES scenario 'families' can be found in Nakicenovic et al. (2000) or in the IPCC Third (Houghton et al. 2001) and Fourth (IPCC 2007a) Assessment Reports.

IPCC insists that there is no basis to assign probabilities to any given scenario (Nakicenovic et al. 2000, cf. also the debates on these issues, e.g. Grübler and Nakicenovic 2001, Schneider 2001, Carter et al. 2007, Fisher et al. 2007). The emission scenarios must also not be interpreted as containing any policy recommendations. In addition, none of these scenarios include any future policies that explicitly address climate change. The more recent newer scenarios explicitly take climate mitigation actions in the scenario set-up into account (e.g. EMF 21, Weyant et al. 2006). However, these new mitigation scenarios have so far only been applied in a few climate/carbon cycle studies (see e.g. Van Vuuren et al. 2008) and are currently not yet much in use by CCIAV studies.

3.2.2 Climate Projections: Global Aspects

Climate projections based on the best currently available coupled climate models and using the previously introduced illustrative SRES emission scenarios have been presented in the recent IPCC AR4 (Meehl et al. 2007). The main findings from (Meehl et al. 2007) focus on two key climate parameters: global mean surface air temperature and global mean precipitation (Figures 3.1 and 3.2). Note that uncertainties associated with precipitation projections are still larger than those associated with temperature projections. Recent advances, however, now allow more robust precipitation projections for large parts of the globe (Figure 3.2; note ratio of coloured vs. white areas and fraction of stippled areas representing varying degrees of model agreement).

Projected global mean surface air temperatures do not differ substantially among scenarios until ~2030 but then start to diverge quickly (Figure 3.1). Global mean surface air temperatures still rise in all scenarios by the end of this century and reach a warming of 1.8 (B1), 2.8 (A1B), 3.4 (A2) and 4.0 (A1FI) °C by 2100 relative to present levels (IPCC 2007e, p. 70, Table TS.6), thereby covering an actual range 1.1 to 6.4°C warming by the end of this century

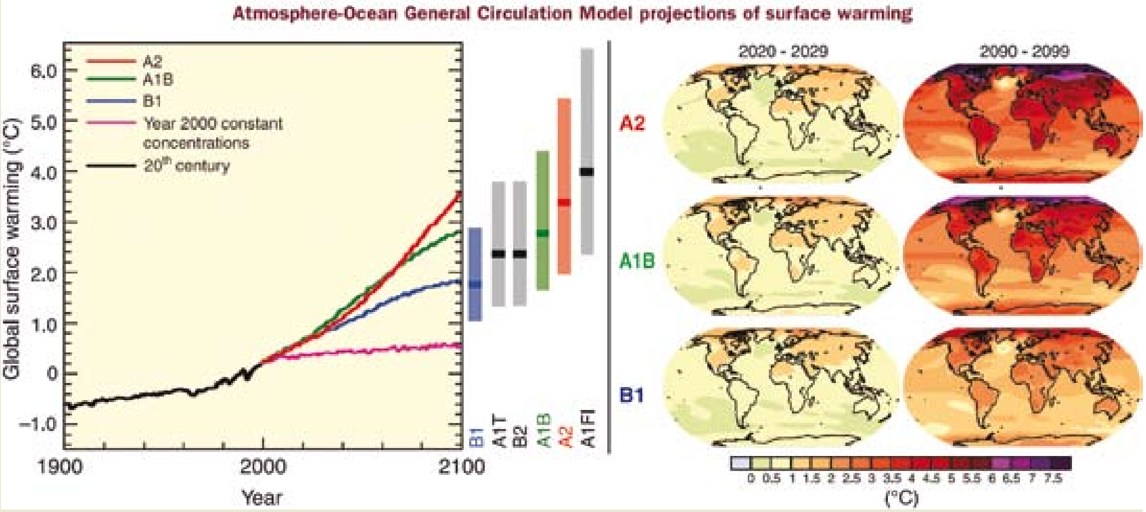

Figure 3.1 Left panel: Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for the SRES scenarios A2, A1B and B1, shown as continuations of the 20th-century simulations. The pink line stands for the experiment where concentrations were held constant at year 2000 values. The bars in the middle of the figure indicate the best estimate (solid line within each bar) and the likely range assessed for the six SRES marker scenarios at 2090–2099 relative to 1980–1999. The assessment of the best estimate and likely ranges in the bars includes the Atmosphere-Ocean General Circulation Models (AOGCMs) in the left part of the figure, as well as results from a hierarchy of independent models and observational constraints. Right panels: Projected surface temperature changes for the early and late 21st century relative to the period 1980–1999. The panels show the multi-AOGCM average projections for the A2 (top), A1B (middle) and B1 (bottom) SRES scenarios averaged over decades 2020–2029 (left) and 2090–2099 (right) (IPCC 2007d, p. 46, Figure 3.2, reprinted with the permission of IPCC. See also IPCC 2007c, Meehl et al. 2007, section 10.4, 10.8, Figures 10.28, 10.29).

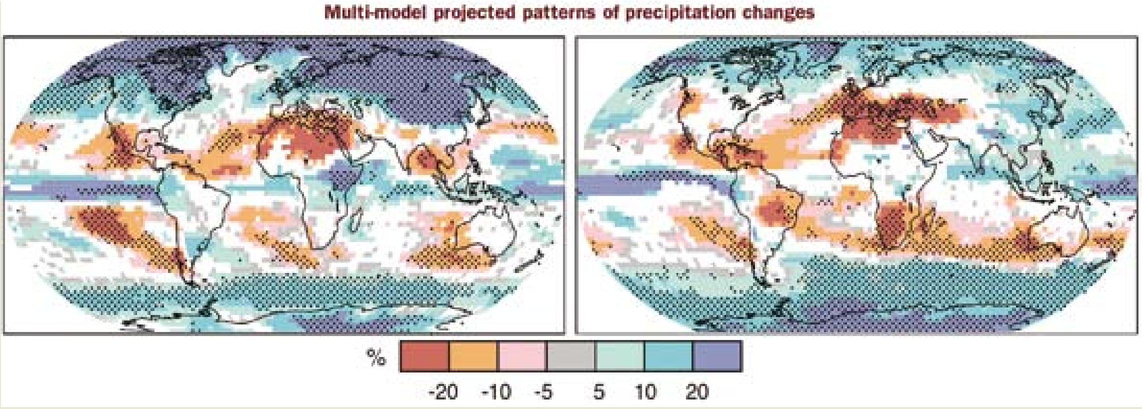

Figure 3.2 Relative changes in precipitation (in percent) for the period 2090–2099, relative to 1980–1999. Values are multi-model averages based on the SRES A1B scenario for December to February (left) and June to August (right). White areas are areas where less than 66% of the models agree in the sign of the change and stippled areas are those where more than 90% of the models agree in the sign of the change (IPCC 2007d, p. 47, Figure 3.3, reprinted with the permission of IPCC. See also IPCC 2007c, Meehl et al. 2007, Figure 10.9).

(33% confidence interval). The regional distribution is such that high latitudes, particularly in the Arctic, warm much faster than low latitudes, and land masses warm much faster than the oceans.

Precipitation is projected to wane further in regions that are already dry today (subtropics, e.g. Mediterranean basin), whereas regions that are relatively wet today tend to become even wetter (high latitudes, inner tropics, Figure 3.2).

While figures 3.1 and 3.2 indicate how climate might change on average and in the long term, no information about short-term variability, extreme events, in particular, is shown. However, short-term variability such as storms of any kind are as relevant as changes in the means, since they can cause serious damage, not least to forests. Current understanding

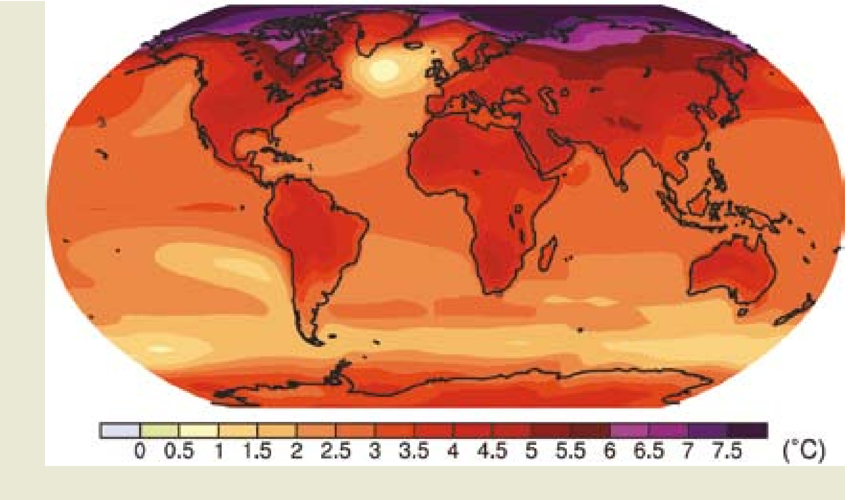

Figure 3.3 Multi-model mean of annual mean surface warming (surface air temperature change, °C) for the scenario A2 by time period 2080 to 2099. Anomalies are relative to the average of the period 1980 to 1999 (Meehl et al. 2007, p. 766, Figure 10.8, reprinted with the permission of IPCC).

and climate models indicate that, for example, future tropical cyclones are likely to be more intense due to the ongoing increases of tropical sea surface temperatures (IPCC 2007c). The projections indicate larger speeds of peak winds and more heavy precipitation events. There are indications that the frequency of tropical cyclones may decrease. However, confidence in those projections is much smaller. Since 1970 the proportion of very intense storms has been observed to increase in some regions, whereas current climate models simulate for that period a much smaller proportion. Similarly, changes in extra-tropical storms are projected; for example, there may be a northward shift of storm tracks.

3.2.3 Climate Projections: Regional Aspects

Although of great interest for studies of impacts and adaption, regional projections are associated with larger uncertainties than global projections. Nevertheless, recent advances in climate models now allow more reliable projections of regional climate change (e.g. Christensen et al. 2007, Figure 11.15 [p. 895], Figure 11.2 [p. 869], Figure 11.17 [p. 901], Figure 11.5 [p. 875]). Within this report, the focus is on four particular regions where several case studies investigate climate-change impacts on forests. Focus areas discussed include the Amazon, South Africa (Box 3.2), Southern Australia, and Northern Europe (Box 3.1). Figure 3.3 shows multi-model mean temperature projections at a scale suitable for these case studies featuring the IPCC SRES A2 scenario.

Special downscaling techniques would need to be applied in order to increase the reliability of regional projections based on global coupled climate models, in particular in the context of assessments of impacts on ecosystems (e.g. Gyalistras et al. 1994, Gyalistras and Fischlin 1999, Jones et al. 2005). Unfortunately, only a limited number of impact and adaptation studies use such techniques, which are of particular relevance in complex terrains where downscaling would actually be a necessity (e.g. Gyalistras et al. 1994, Fischlin and Gyalistras 1997, Gyalistras and Fischlin 1999).

3.2.4 Scenario Clusters

The four scenario clusters *fast growth*, *growth*, *stable*, and *unavoidable* stress commonalities among scenarios in the current trends of emissions and weigh possible later differences among pathways in the second half of this century much less.

Growth: With no major technological changes and without stringent climate policies, emissions are expected to continue growing and would still do so at the end of the century as captured in the IPCC SRES reference scenarios A1FI, A1B and A2. As a consequence, atmospheric CO_2 concentrations are expected to continue rising for quite some time after 2100 and the climate system will be out of equilibrium for centuries thereafter (e.g. Christensen et al. 2007, IPCC 2007d, IPCC 2007c, Meehl et al. 2007).

Stable: With major technological changes CO_2 emissions are expected to start declining during the course of this century as captured by the IPCC

SRES reference scenarios A1T, B2 and B1. As a consequence, atmospheric CO_2 concentrations are expected to approach a new equilibrium towards the end of this century (e.g. Christensen et al. 2007, IPCC 2007d, IPCC 2007c, Meehl et al. 2007). Such a stabilization of atmospheric CO_2 concentrations would be in accordance with the ultimate goal of the UNFCCC in its Article 2. However, whether the particular stabilization levels of the scenarios belonging to this cluster would avoid any dangerous interference with the climate system is and remains an unanswered question (Solomon et al. 2009). Moreover, judgements about dangerous interference cannot be properly addressed merely on scientific grounds (e.g. IPCC 1996).

The majority of CCIAV studies fall into the cluster *growth* while only a limited number look at scenarios belonging to the cluster *stable*. Studies assessing minimal adaptation or scenarios facing particularly rapid climate change are special cases of special interest in the context of this report. Consequently, two additional clusters have been introduced: *unavoidable* and *fast growth*.

Unavoidable: IPCC AR4 published for the first time multi-model simulations of climate system responses to an arbitrary freeze of atmospheric CO_2 concentrations at year 2000 levels (Figure 3.1, left panel, pink line) (IPCC 2007d, IPCC 2007c). This scenario is artificial and is very unlikely to be attainable in reality, since it implies as of 2000 negative and later zero emissions (unless atmospheric CO_2 would be sequestered in large amounts by forests and new technologies). However, the resulting climate scenarios allow the assessment of minimal impacts and minimum adaptation requirements.

Fast growth: Since about 2000, global emissions have been accelerating. CO_2 emissions rise currently by over 3% annually, whereas annual growth rates in the 1990s were on average only 1.1% (Raupach et al. 2007). These trends are not captured by the commonly used IPCC emission scenarios and even more importantly they are beyond the emission rates of the SRES reference scenario with the highest emissions for the present, i.e. the A1FI scenario. It is clear that this most recent trend in global emissions forms a particular challenge for humanity, including the forest sector (e.g. Schellnhuber et al. 2006, Ramanathan and Feng 2008), given the multi-millennial lifetime of the human CO_2 perturbation.

Whenever possible, this report refers back to these scenario clusters while discussing impacts, adaptation options, vulnerabilities and policy options.

3.3 Global Changes and Impacts

Given a climate-change scenario (cf. sub-chapter 3.2.4) and state-of-the-art Dynamic Global Vegetation Models (DGVMs, see Glossary), one can project future land vegetation under any climate-change scenario (e.g. Prentice et al. 2007). Unfortunately models of this type represent forests only at the biome level, i.e. they work with 'plant functional types' (PFT, see Glossary) instead of actual species. Other forest models are available, such as patch dynamics models that do operate at the species level and can also be applied in a CCIAV assessment context (e.g. Kirschbaum and Fischlin 1996, Box 1–4, p. 105). Patch models are most attractive for being able to mimic realistically the temporal characteristics of responses to a changing climate and their species specificity. However, they have the disadvantage of a limited geographical applicability and most of them are limited to the temperate and boreal domain (e.g. Solomon and Leemans 1990, p. 312), whereas DGVMs have the advantage of being applicable globally. Thus, current projections at the global scale are based on DGVM simulations such as those provided by IPCC (Figure 3.4, Table 3.1, Fischlin et al. 2007)

Table 3.1 Major biome changes projected by LPJ forced by a scenario from cluster *stable* (sub-chapter 3.2.4, ECHAM5 B1) and from cluster *growth* (sub-chapter 3.2.4, HadCM3 A2) (assumed forest/woodland area estimates for 2000: 41.6 Mkm^2 from Bonan 2002, Sabine et al. 2004, see Figure 3.4 for maps on underlying ecosystem changes and numbers used to denote types of vegetation changes)

Vegetation change	Scenario *stable* area change ($\Delta T_{\text{2100-preind.}}$ +2º) (Mkm^2)	Scenario *growth* area change ($\Delta T_{\text{2100-preind.}}$ +3.8ºC) (Mkm^2)
6: Forest/woodland decline	–4.1 (–12%)	–12.1 (–29%)
1+2+3: Forest/woodland expansion	12.7 (+31%)	16.6 (+40%)
1+2+3–6: Net forest/woodland change	8.6 (+21%)	4.5 (+11%)

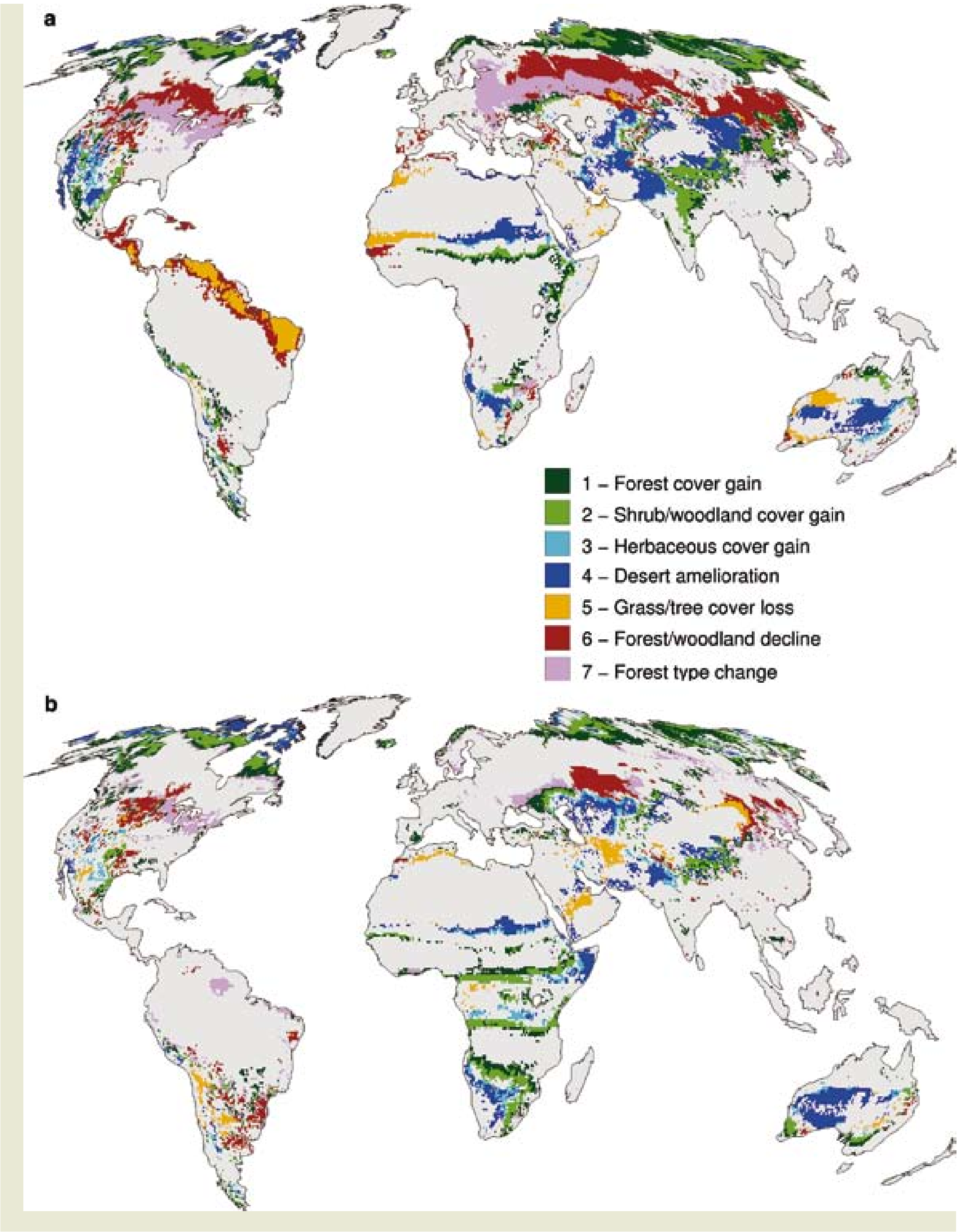

Figure 3.4 Projected appreciable changes in terrestrial ecosystems by 2100 relative to 2000 as simulated by DGVM LPJ (Sitch et al. 2003, Gerten et al. 2004) for two scenarios forcing two climate models: (a) scenario cluster *growth* (sub-chapter 3.2.4, HadCM3 A2), (b) scenario cluster *stable* (sub-chapter 3.2.4, ECHAM5 B1) (Lucht et al. 2006, Schaphoff et al. 2006). Changes are considered appreciable and are only shown if they exceed 20% of the area of a simulated grid cell (Fischlin et al. 2007, p. 238, Figure 4.3, reprinted with the permission of IPCC. See also Table 3.1).

The same climatic change impacts forests in a different manner, depending on the locally specific bioclimatic and edaphic conditions and the species composition. Furthermore, the management of forests and land use will modify the ecological responses of the ecosystems to climate change. This further emphasizes the need to analyze the impacts of climate change in a local context to gain a better

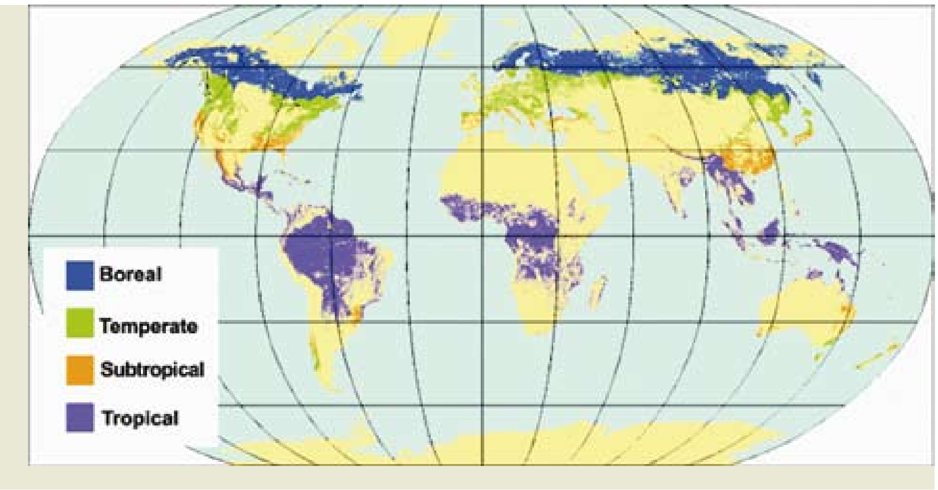

Figure 3.5 The four forest domains: boreal, temperate, subtropical and tropical as distinguished in this report (FAO 2001b, p. 5, Figure 1–4).

understanding of how climate change may affect provisioning and other services in the future, including the potential for forestry. This chapter will therefore make a separate CCIAV assessment for each of the four domains (see Chapter 1): boreal (sub-chapter 3.4), temperate (3.5), subtropical (3.6) and tropical (3.7) (Figure 3.5).

The following text is organized in such a way that both views, i.e. ecosystem services and the recurrent themes view, as alluded to above, are covered. The boreal domain serves as a model case and will be discussed in greater depth than the other domains. Topics covered for other domains treat complementary aspects, in particular those that call for special emphasis in the respective domain. Some of the regional biases in the following ought to be seen as exemplary and otherwise as being rather coincidental, since this chapter, given its scope, had to be written by a relatively small team of authors.

3.4 Boreal Domain

3.4.1 Types of Boreal Forests

The boreal forests (forests and other woodlands) cover 1270 million ha of land including boreal coniferous forests (730 million ha), boreal tundra (130 million ha) and boreal mountains (410 million ha), mainly in North America (Canada, Alaska), the Nordic countries (Finland, Sweden, Norway) and Russia (FAO 2001b). The boreal biome is the second largest terrestrial biome and has 33% of the Earth's forested area (FAO 2001b, Fischlin et al. 2007). These circumpolar forests (Figure 3.5) represent the environmental conditions characterized by the annual mean temperature of –5°C to +5°C, and the annual precipitation is 300–1500 mm. In these conditions, the potential evapotranspiration is about 400–450 mm but the actual evapotranspiration is substantially less (300–350 mm). The mean maximum temperature of the warmest summer month is more than 10°C, and the duration of summer is not longer than four months. The boreal zone is humid and typically characterized by coniferous tree species. Because of the cold winter and thin cover of snow, permafrost covers large areas in Alaska and the high-continental boreal zone in Canada and Siberia, where soil temperature regularly remains below 0°C even in summer.

The mean stem wood stocking in the boreal forest is about 120 m^3/ha, with a total mean stem wood growth of 1.6 m^3/ha/a (Table 3.2). In these forests, the most important coniferous species are pines (*Pinus*), spruces (*Picea*), firs (*Abies*), larches (*Larix*), junipers (*Juniperus*), thujas or cedars (*Thuja*) and hemlocks (*Tsuga*), while the most common deciduous species in these forests are poplars (*Populus*), birches (*Betula*), willows (*Salix*), and alders (*Alnus*). Most boreal tree genera occur throughout the zone representing transcontinental distributions across Eurasia or North America. The number of conifer species is greatest in North America, but also large in the southern part of the Far East. The number of tree species is particularly small in the north-western areas of Eurasia, where Scots pine (*Pinus sylvestris*) and Norway spruce (*Picea abies*) dominate the forested landscapes.

Table 3.2 Stocking and growth of forests in the major boreal forest regions (Kuusela 1990, FAO 2001b).

Region	Stocking, m^3/ha	Net annual growth, m^3/ha/a
Alaska	280	0.8
Canada	110	1.7
Nordic countries	90	3.3
Russia	130	1.4
Total mean	120	1.6

Table 3.3 Forest resources in the boreal regions (Kuusela 1990, FAO 2001b).

Region	Growing stock (10^9 m^3)	Net annual increment (10^6 m^3)	Annual removals (10^6 m^3)
Alaska	1.3	3.6	3.1
Canada	23.0	356.0	152.0
Nordic countries	4.4	158.0	102.0
Russia	67.0	750.0	357.0
Total	95.7	1300.0	642.0

3.4.2 Main Services Provided

Globally, timber production and carbon sequestration are the main forest goods and services, but the boreal forests are also important for conserving global biodiversity and supporting the production of many other goods and services. Their general temperature limitation results in particular characteristics, such as a higher production of humic substances which may lead to particular soil characteristics and the production of non-wood products such as berries and fungi.

3.4.3 Current Opportunities and Vulnerabilities

Timber: The total growing stock of trees in the boreal forests is 100 000 million m^3, of which 80 000 million m^3 represent coniferous tree species (Table 3.3). Boreal forests stock is about 45% of that of all forests and about 50% of that of the coniferous species. This stock increases by 1300 million m^3/a, which corresponds to about 30% of the global forest growth. The coniferous species growth is about 45% of that of the global coniferous net production. Annually about 600 million m^3 are harvested, which represents 20% of the global removal: 500 million m^3 are softwood corresponding to 45% of the global softwood harvest. 500 million m^3 are industrial wood corresponding to 37% of the global industrial wood harvest. The boreal forests in northern Europe or Fennoscandia (including Norway, Sweden, Finland and north-western Russia) provide about 40% of the timber used in Europe on 85% of the total forest area in Europe (956 million ha).

Carbon: The boreal region has been estimated to contain a total of 703 Pg of carbon and about 30% of all the carbon contained in the terrestrial biomes. (Symon et al. 2005, p. 550). Recent estimates by IPCC (Fischlin et al. 2007) that include soil carbon of forest soils to a depth of 3 m (Jobbagy and Jackson 2000) give a different picture: Boreal forests alone contain only 207 PgC, which corresponds to about 13% of all carbon contained in forests. This correction is also in line with other studies since the IPCC Third Assessment Report (Kauppi 2003). In Finland roughly three-quarters of this carbon is held in soils and can be as high as 88% (Kauppi et al. 1997), since cold temperatures slow decomposition resulting in an accumulation of soil carbon. The carbon budget of the boreal forests indicate a net sink between 0.5 and 2.5 MgC/ha/a (Shvidenko and Nilsson 2003). However, given the relatively small annual growth rates vis-à-vis the high rates of net felling, boreal forests are most sensitive to disturbances and any interannual variability in harvesting (Kurz and Apps 1999). Unfortunately, the global forest statistics exclude any changes in the frequency and severity of disturbances, which makes it difficult to assess the source/sink relationship and its changes over time.

Detailed analyses of forest inventory data, together with observed changes in disturbance over time, indicate that Canadian forest ecosystems changed from a modest sink (0.075 GtC/a) between 1920–1970 to a small net source of 0.050 GtC/a as of 1994 (Kurz and Apps 1999). In Russia between 1983 and 1992, managed forests from the European part were a sink of 0.051 GtC/a, while the less intensively managed Siberian forests were a net source of 0.081–0.123 GtC/a. (Shepashenko et al. 1998). These estimates are based on bottom-up methods that exclude factors such as CO_2-fertilization (e.g. Schimel et al. 2001), nitrogen deposition (e.g. Kauppi et al. 1992) and/ or climate change (e.g. Zhou et al. 2001, McMillan et al. 2008). This may have biased these estimates, a view which is also supported by remote sensing-based estimates (e.g. Myneni et al. 2001). Growth of tree species in the boreal conditions and elsewhere representing C_3-plants is sensitive to elevating CO_2 whenever the availability of nitrogen or other nutrients is not limiting (e.g. Jarvis and Aitken 1998).

Biodiversity: In general, the number of species per unit area is low at high latitudes. However, the total species richness in the boreal region is greater than in the poleward tundra, but less than in the temperate forests at mid-latitudes. Roughly, the species richness is correlated to the productivity of an ecosystem and, thus, increasing along the meridional temperature gradients across the boreal vegetation zone (Ympäristöministeriö 2007). The boreal forests frequently give way to mires and small lakes, leading to a mosaic structure of forest and wetland, which provides a huge variability in available habitats and, thus, increases the species and genetic richness at the landscape level. On the other hand, the boreal forests are characterized by large numbers of individuals of few tree species with a wide ecological amplitude, in contrast to tropical forests that sustain a small number of individuals of many species with a narrow ecological amplitude. Genetic diversity in any species is in part the result of the opportunity the species offers for gene recombinations. The genotypic variability represents adaptations to the specific conditions of local environments, suggesting a high degree of local adaptation within the boreal domain.

In the continental parts of the boreal forests, fire controls the natural dynamics of the forests and consequently influences biodiversity. Some species are adapted to using the resources provided by standing and lying burnt trees in different stages of decay. In particular, fire sustains a set of species in early post-fire communities that are distinct from later successional species. These include species from a range of groups, including birds, beetles, spiders and vascular and non-vascular plants (Esseen et al. 1993). If regular fires are absent, many species can build large populations only in situations with a reduced species richness. Such effects can be observed in many managed boreal forests in Nordic countries. Moreover, where effective fire-fighting has made fire events rare, species which depend on fire-modified habitats are now threatened. In Finland, 14 species, mostly beetles (*Coleoptera*) and bugs (*Hemiptera*), associated with burnt forest land are threatened (Ympäristöministeriö 2007).

Despite their relatively low number, the species in managed boreal forests represent an important part of the global biological diversity. This holds good for many countries in the boreal domain such as Finland (see also Box 3.1), where more than 90% of the forest area is managed for timber production. There the estimated total number of species is about 50 000, out of which about 43 000 are known. The reason for the relatively low total number of species is the short time that has elapsed since the last glaciations (10 000 years ago), with the consequence that immigration is still going on (e.g. Johnstone and Chapin 2003, Callaghan et al. 2004, Harris 2008). These species and the subsequent biodiversity involve a large contribution from natives of the eastern taiga (flying squirrel, Ural owl, Siberian jay, to name just a few). Most of these taiga species are connected with spruce forests. On the other hand, a high proportion of the forest species (20–25%) are dependent on dead wood (800 coleopterans, 1000 dipterans, 1000 fungi, 200 lichens, etc.). Many of these species are specialized in living on recently burnt tree material, while a high proportion live in peatland forests or on mires (Kellomäki et al. 2001, Ympäristöministeriö 2007).

3.4.4 Projected Future Impacts and Autonomous Adaptation

The boreal domain will experience more warming than equatorial zones (Anisimov et al. 2007, Christensen et al. 2007). Consequently, and because boreal forests are generally temperature limited, they are expected to be particularly impacted by future climate changes as stated by IPCC (Kirschbaum and Fischlin 1996, Anisimov et al. 2007, Fischlin et al. 2007).

Biome shifts: A key impact of climate change will be the effect on the living conditions of many species and their distribution will be altered. Although evidence from past climate changes shows that species respond individually, the boreal domain is nevertheless expected to shift polewards as an entire biome. In Canada, Price and Scott (2006) used the IBIS model to predict changes in the extent of the boreal and sub-boreal forests (Figure 3.6). Their work predicts a marked northward migration of the boreal forest and a considerable increase in parkland or savanna and grassland in previously boreal zones in central and southern Canada. Depending on the model scenario, carbon stocks increase or decrease in North America with climate change 'business as usual' scenarios by 2100 (Neilson et al. 1998, Price and Scott 2006). This difference is affected by different assumptions in the models and depends considerably on response to CO_2-fertilization and expected rates of fires. Thompson et al. (1998) projected fewer old-growth forests and more young forests across boreal landscapes under an increased fire regime.

Productivity: A main factor underlying the future impacts of climate change on the dynamics and vulnerability of boreal forests is how climate change affects the primary productivity of those forests. In the boreal domain, primary productivity is in general expected to increase through the following three main mechanisms: (i) CO_2-fertilization; (ii) temperature increases and lengthening of growing seasons; and (iii) precipitation increases under water-limited conditions that lead to a greater water availability. These effects tend to enhance regenerative, physiological and growth processes of trees. Based on the find-

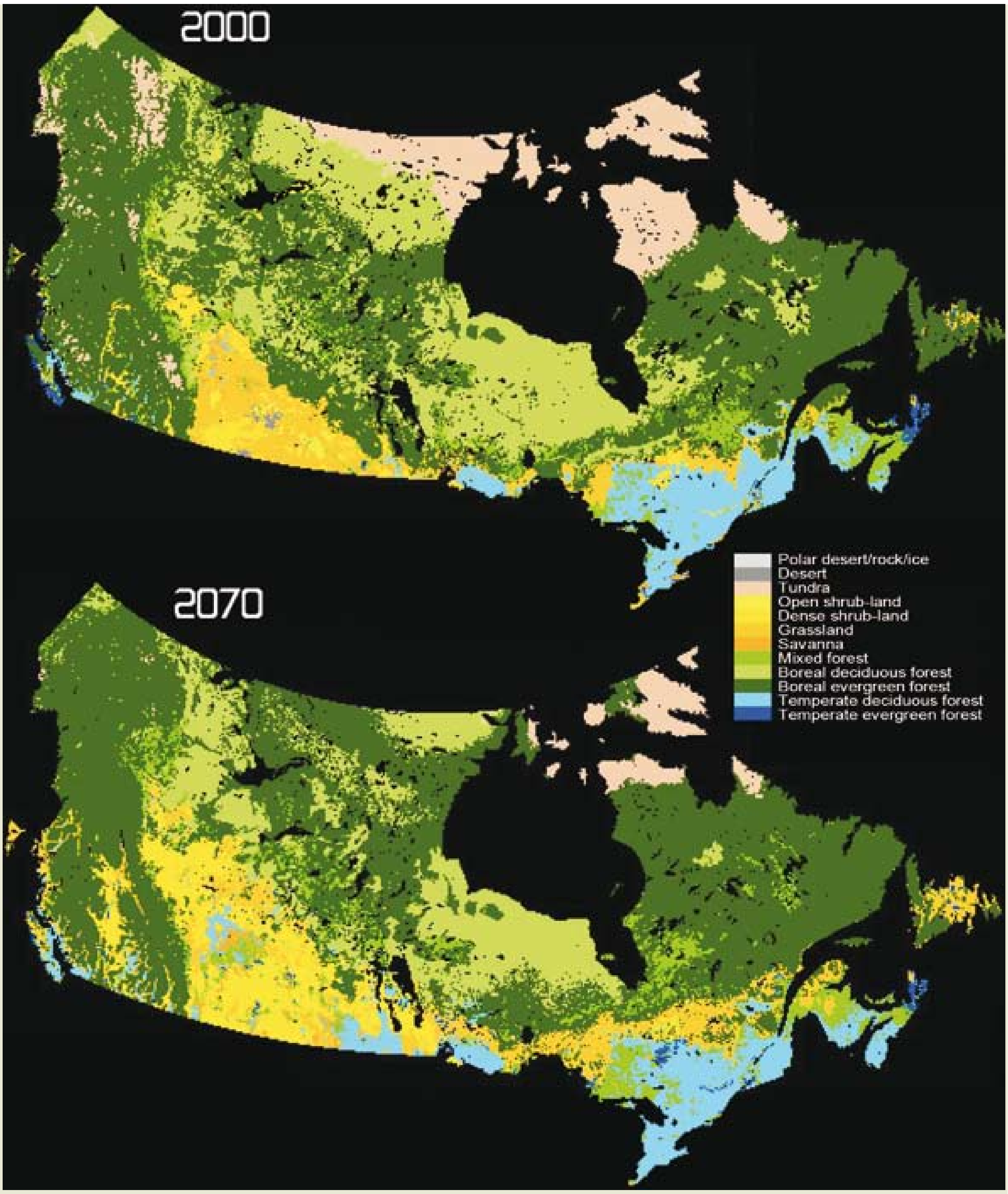

Figure 3.6 Distribution of major vegetation types as simulated by the vegetation model IBIS for 2000 and under a scenario from cluster *growth* (IPCC ISN92a) in 2070 in Canada. Note the band of grasslands extending across Ontario and south-western Quebec incorrectly simulated within a zone of otherwise continuous forest, suggesting the difficulty in accurately projecting future vegetation cover (Price and Scott 2006, reproduced with permission of the authors).

ings of satellite monitoring, IPCC reports a recent increase in global net primary production (NPP) by 12% in Eurasia and by 8% in North America from 1981 to 1999 (Fischlin et al. 2007, Rosenzweig et al. 2007). The underlying studies relate these changes to the elevation of the ambient atmospheric CO_2-concentration, lengthening of the growing season, nitrogen deposition, or changes in management. These estimates are well in line with the greening of the Northern Hemisphere as observed via remote sensing (e.g. Myneni et al. 2001), which is most probably due to the lengthening of the growing season at high latitudes due to the elevation of spring temperatures. The model-based analysis for Finland (Box 3.1) illustrates how climate change may affect forest growth in the boreal domain.

Box 3.1 Impacts of climate change on the growth of managed boreal forests in Finland (Kellomäki et al. 2008).

The simulations cover 26 million ha of forest land represented by the permanent sample plots of the Finnish National Forest Inventory located across the boreal forest zone at N 60°–70°. The current climate (1961–1990) used in the reference simulations represented the same spatial scale as the grid of the permanent sample plots of the National Forest Inventory. The climate-change scenarios were based on the IPCC SRES A2 emission scenario (cluster *growth*). By 2070–2099, the mean temperatures are projected to increase almost 4°C in the summer and more than 6°C in the winter. The annual precipitation is expected to increase by 10% in southern and up to 40% in northern Finland, mainly in winter. At the start of simulations in 1990, the atmospheric concentration of CO_2 was 350 ppm, compared with 840 ppm at the end of simulation in 2099. Current management practices were assumed in the simulation (Ruosteenoja et al. 2005).

Figure 3.7 shows that the growth integrated over the tree species varies currently from less than 1 m^3/ha/a in the north up to 6 m^3/ha/a in the south of Finland depending on the site fertility, tree species and age (or developmental phase) of tree populations. Climate change results in the largest change in growth in the northernmost part of the boreal region; i.e. any increase to a low growth rate may result in a large percentage change. Throughout northern Finland and Canada, the growth increase is several tens of percentages. In southern Finland, the increase is much less, ranging mainly from 10% to 20%, i.e. the integrated growth may increase up to 7 m^3/ha/a in the south. This implies that the growth at the rate of 3–4 m^3/ha/a currently prevailing in the central part of Finland may shift up to the Arctic circle (66°N). In southern Finland the growth may increase up to 12% in this century due to climate change. This is substantially less than in northern Finland, where the growth may be doubled compared to the growth under the current climate. Over the whole country, an increase of 44% was obtained, mostly effected by the large increase in the northern part of the country. However, the changes in the growth of Norway spruce are in many locations (mainly south from the latitude 62°N) small or even negative due largely to the more frequent drought periods occurring during the latter part of this century.

The increase in forest growth in the northern boreal region implies an increase in the potential timber harvest and carbon sequestration. The simulations showed that under southern boreal conditions the potential cutting drains may increase up to 50% by the end of this century. In the boreal forests of northern Finland, the increase is much larger (up to 170%), but there the absolute value (3 m^3/ha/a) is still less than two-thirds of that in the south (5 m^3/ha/a). At the same time, the duration and depth of soil frost will reduce substantially, which makes the winter-time timber harvest more difficult and reduces the overall profitability of timber harvest (Venäläinen et al. 2001).

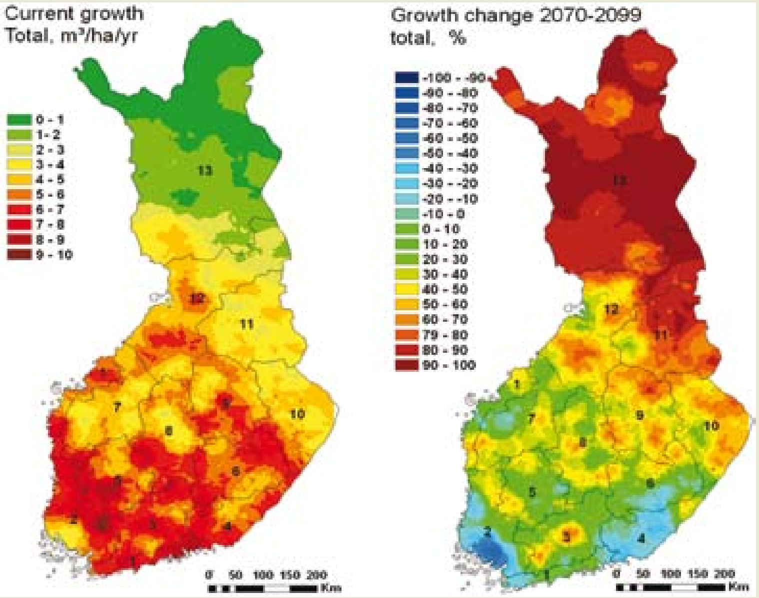

Figure 3.7 Current growth of stem wood (left) and the percentage change by the end of this century if the change in climate as described in the text (cluster *growth*) is assumed (numbers denote provinces within Finland)(Kellomäki et al. 2008).

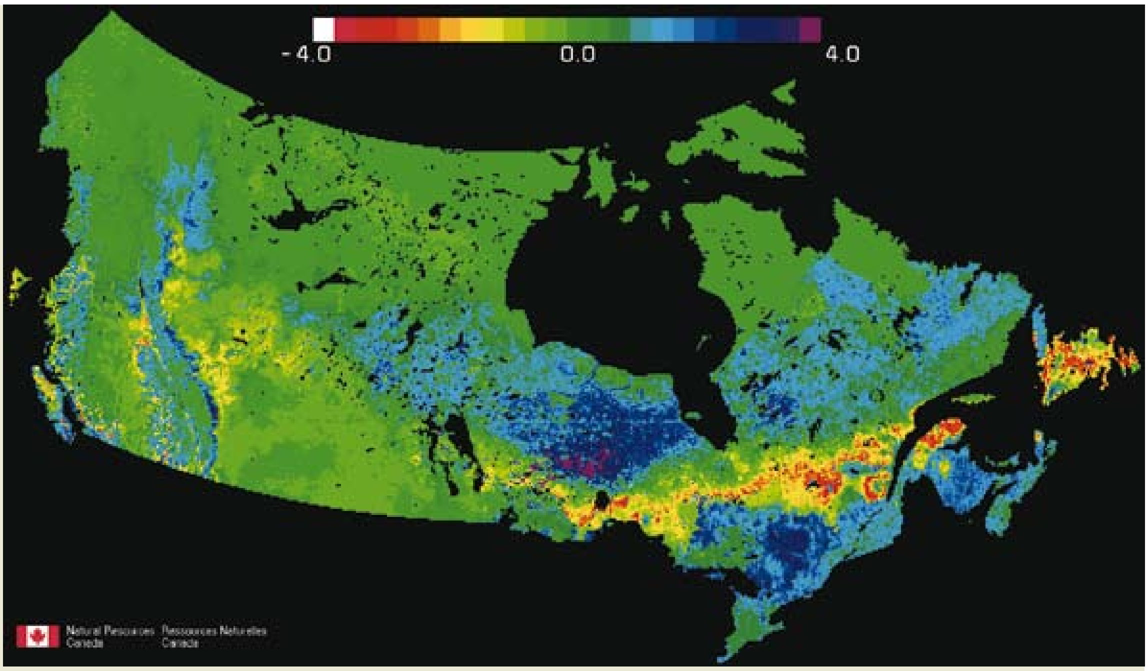

Figure 3.8 Changes in NPP (kgC/m²/a) as simulated by IBIS for the period 2070 relative to 2000 (Price and Scott 2006, reproduced with permission of the authors) for a scenario from cluster *growth* (IPCC ISN92a).

Similar results were found for Canada by Price and Scott (2006) with broad increases on average for the boreal region in excess of 0.2 kgC/m²/a. They suggested a wide range of variability, however, with some locations (central western and central eastern areas) showing only small increases in NPP, while other areas, such as those west of Hudson Bay, were found to have an increase of biomass by up of 0.5 kgC/m²/a (Figure 3.8). Nevertheless, they observed disparity among the results projected, depending on the emission scenarios and/or the various climate models used (*growth*: IPCC ISN92a, SRES A2; *stable*: IPCC SRES B2; GCMs: HADCM3, CGCM2, CSIRO Mk2). The MC1 model of Neilson (Lenihan et al. 1998, Daly et al. 2000, Bachelet et al. 2001) actually projects broad carbon losses for much of the same forests, which illustrates the complexity of these issues and raises questions and key uncertainties about the assumptions used in the models.

These model projections are illustrative examples that are based on complex assumptions. They encompass not only changes in climate such as increasing precipitation and warming temperatures, but also other effects such as CO_2 fertilization and species migrations. Some of these assumptions are associated with considerable uncertainties. The availability of sufficient nutrients or physiological acclimation to elevated CO_2 concentrations could significantly limit and reduce, respectively, the realized productivity gains from the CO_2 fertilization. An assumption of optimal dispersal of species results in projections of rapid shifts in geographical ranges.

Hungate (2003) argued that DGVM models make unrealistic assumptions about nitrogen availability. Since those nitrogen requirements as formulated in the models could not be met in reality, the model projections would be too optimistic, particularly in respect to sequestration services. A slackening of carbon sequestration would then result in an acceleration of climate change, which could lead eventually to environmental conditions where primary productivity would start to decrease even in the boreal domain. Fischlin (2007, section 4.4.1) discusses these issues in detail.

Current DGVMs also assume plant functional types that always have sufficient dispersal capabilities to track climate change optimally (e.g. Prentice et al. 2007). Real plant species, however, given the evidence from past climate changes (cf. Fischlin et al. 2007, section 4.4.5), are known to have limited dispersal capabilities. This is of particular relevance for tree species that are generally not expected to be able to track the rapid climate changes projected for this century (cf. Fischlin et al. 2007, section 4.4.5). This would lead to considerably lagged responses to climate change, perhaps century-long ones and, particularly where major soil formations are necessary, and the boreal timberline would advance polewards considerably slower than projected by current DGVMs (cf. Fischlin et al. 2007, section 4.4.5, 4.4.6).

In the boreal domain, climate change can also cause a decline in the primary productivity as has been documented for a substantial portion of forests in North America due to more frequent drought conditions. The concurrent increase in the productivity of the tundra, probably due to longer and warmer growing seasons, will in the long run cause northern boreal forests to invade the tundra, while boreal forests at the southern ecotone are likely to retreat due to increasing drought, insects and more prevalent fires (Denman et al. 2007, Fischlin et al. 2007, Figure 4.4–2). Since the rate of loss at the southern ecotone due to relatively fast processes such as fire is likely to be higher than the rate of gain at the northern ecotone due to the slow growth conditions, the overall effect of these two processes for the boreal forests is likely to be negative during the transient phase, i.e. until a new equilibrium between climate and vegetation is established. In this context it is also important to remember that climate-change scenarios from cluster *growth*, let alone *fast growth*, are generally not yet available beyond 2100, yet climate itself has not yet reached stabilization and, thus, the impacts assessed up to 2100 are not representative for the situation in the next century and beyond (compare also Box 3.1). However, in equilibrium a general increase in deciduous vegetation at the expense of evergreen vegetation is predicted at all latitudes, although the forests in both the eastern USA and eastern Asia appear to be sensitive to drought stress and already show declines under some scenarios in this century.

Box 3.1 illustrates these processes. While forest growth is projected to increase in general in Finland, the growth conditions in the southern boreal region are reduced because of the declining growth of Norway spruce due to the increasing frequency of drought periods. In the north, the primary productivity of the forest ecosystems may be increased substantially, but it will still be less than that currently present in the south. However, the special features of northern forests and terrestrial ecosystems may be diminished even above the current timberline. This development is probably quite inevitable, and little can be done in order to conserve the present character of the northern boreal forests. The northern forests may provide many opportunities for the forestry and timber industry, while the forest environment may turn suboptimal, e.g. for reindeer husbandry and recreation business, which are currently the main uses of the sub-artic and sub-alpine landscapes in the north.

Frost: In the boreal forests, the timing of bud-burst is related to spring temperatures, as found for birches and Scots pine (Myking and Heide 1995, Häkkinen et al. 1998). The bud-burst is preceded by low chilling temperatures during winter. Even under elevated temperatures, the chilling requirements of trees are likely to be fulfilled, and earlier bud-burst may be expected. On the other hand, there is no empirical evidence that earlier bud-burst under climatic warming would lead to catastrophic frost damage. On the contrary, in old provenance transfer experiments, where northern provenances of Norway spruce and Scots pine were grown in southern Finland, thus undergoing considerable ‘climatic change’ (increase of temperature sum by up to 600 degree days), bud-burst was hastened, but growth was also increased (Beuker 1994, Beuker et al. 1996). This is in line with the findings that in the phase of bud-burst the frost hardiness of Scots pine is still remarkable, i.e. it then still tolerates frost conditions below –20°C.

Storms: Strong winds blow down and break trees with large economic losses in timber production and productivity of forest ecosystems. The occurrence of wind damage is tightly linked with the occurrence of high wind speeds. The risk of wind damage is increasing with the maturing of trees, taller trees being at higher risk than shorter ones. On average, wind damage does not occur under boreal conditions up to a maximum mean regional wind speed of 15 m/s given that gusts also stay below 30 m/s (Peltola et al. 1999).

The overall risk of wind damage is greatest in stands adjacent to newly clear-felled areas and within newly thinned stands, especially if stands not previously thinned are suddenly thinned intensively. This is because wind is able to penetrate deeper into the canopy following thinning, with a subsequent increase in the wind load imposed on the trees, while dense stands dissipate incoming winds. The probability of damage decreases, however, with the time elapsed since thinning. However, changes in the occurrence of extreme wind speeds, along with the changing climate, are of the greatest importance. Except for the increasing risk of local wind extremes, it is still an open question whether climate change may induce changes in boreal wind patterns. However, the higher frequency of strong winds during periods of unfrozen soils in late autumn and early spring might be the most alarming scenario (Päätalo et al. 1999, Peltola et al. 1999, Venäläinen et al. 2001), although current climate-change scenarios do not allow boreal-domain projections for changes in storm patterns, i.e. intensities, frequencies and/or exact geographical or seasonal occurrence (cf. sub-chapter 3.2). The changing climate may decrease the duration of snow cover and frozen soil with a reduction in the overall anchorage and an obvious increase of wind-induced forest damage.

Snow: The severity of snow damage mainly depends on the amount of snowfall and the attachment of snow on crowns. Snow attachment is probable at temperatures around 0°C. In these conditions, snowfalls of 20–40 cm or more appear to represent a low to moderate risk, whereas snowfalls of about 60 cm or more increase damage risks to very high

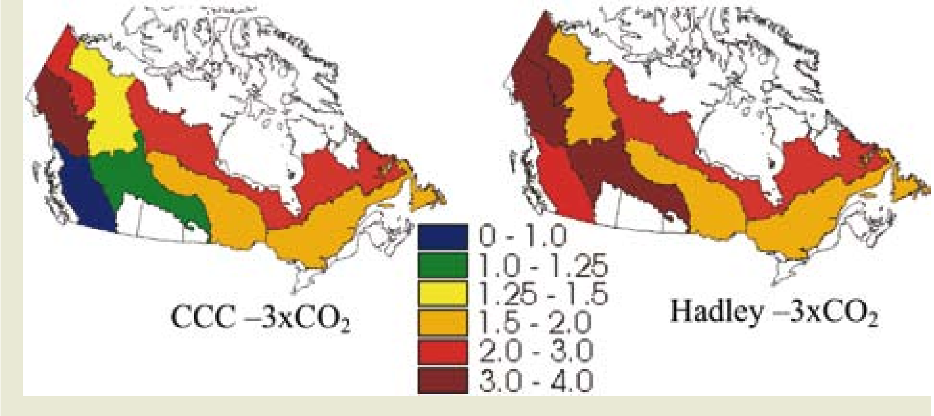

Figure 3.9 Projections of changes in area burnt based on weather/fire danger relationships shown as a ratio relative to a 1975–1990 baseline. These results suggest a 75–120% increase in area burnt (average ratios 1.75 and 2.2) by the end of this century according to scenarios from cluster *growth* ($3xCO_2$) as generated by two climate models (Canadian CCC and Hadley Centre HADCM3) (Flannigan et al. 2005 Figure 5, p. 11–12, copyright Springer. Reprinted with permission of Springer Science and Bussiness Media).

levels (Päätalo et al. 1999). Wind speeds less than 9 m/s appear to intensify the risk of snow damage otherwise induced by the accumulation of wet snow, whereas snow would more probably be dislodged from the tree crowns by wind speeds greater than 9 m/s (Peltola et al. 1999). In the Nordic countries, the mean return period of severe snow damages is 5–15 years.

A changing climate may affect the risk of snow damage in several ways. The share of snowfall from the total winter precipitation may be reduced with an obvious reduction of risk. On the other hand, increased winter precipitation may increase weather episodes with temperatures that enhance the attachment of snow and the concurrent accumulation of snow on tree crowns. Furthermore, increasing winter precipitation may lead to more intense snowfall and accumulation of snow. This would increase risks of snow damage if the temperature and wind conditions favour excessive snow accumulation, as seems to be the case for boreal conditions during the next 50 years (Venäläinen et al. 2001). These factors probably balance in such a way that at higher altitudes or most northern areas the risk of snow damage may increase, but at lower altitudes or areas outside the northern regions the risk may decrease. Later in this century, the risk of major snow damage will probably reduce due to a reduction of precipitation in the form of snow.

Fire: Temperature and precipitation are the main climatic factors affecting incidences of wildfires in forests. However, since precipitation is projected to increase with temperature in some cases (e.g. Bergeron 1991, Carcaillet et al. 2001) but to decrease in others (e.g. Hallett et al. 2003, Lynch and Hollis 2004), fire risk is expected both to increase and decrease with climate change (cf. Fischlin et al. 2007, section 4.4.5).

In boreal conditions, less rainfall during the growing season leads to more frequent fires during the same year (Flannigan and Wotton 2001). In Canada and Alaska, the temperature has been found to be the most important predictor of area burnt, with warmer temperatures associated with increased area burnt annually (Flannigan et al. 2001, Flannigan and Wotton 2001, Duffy et al. 2005, Flannigan et al. 2005). Boreal forest fire seasons have two peaks: In early spring large amounts of dry plant debris from the previous summer, without much green vegetation, increase the probability of fire ignitions (Zackrisson 1977). Furthermore, earlier melting of snow may dry out soils unless precipitation is simultaneously increased. The second peak is during the late summer when soils have dried out at a sufficiently deep level. Wotton and Flannigan (1993) estimated that the fire season length in Canada will increase by 22% or by 30 days, on average, in response to a climate scenario from cluster *stable* ($2xCO_2$). However, seasonal variability in precipitation may affect the development of the forest fire potential considerably. On the other hand, increased precipitation has also been found to mask the effects of warmer temperatures on forest fire (e.g. Bergeron and Archambault 1993). Flannigan et al. (2005) modelled two possible fire change scenarios for Canada under a scenario from the cluster *growth* (Figure 3.9). The models do not show strong concurrence except that the area burnt will increase by the largest amount in the extreme north-west area of the boreal region. More recent models for Alaska and northern and western Canada predicted even higher rates of increased fire, of up to 5.5 times the recent baseline, using scenarios from the clusters *growth* (IPCC SRES A2) and *stable* (IPCC SRES B2) (Balshi et al. 2008).

In more inhabited northern Europe, thanks to fire control, forest fires are rare, the percentage of forest land burnt annually being less than 0.05%. The mean size of fires is less than one hectare (Zackrisson 1977). The return period of fires is 50–100 years on average on dry upland sites, and much longer for moist upland sites. In boreal conditions, one to two weeks without rain is needed to significantly increase the fire risk even under current precipitation (250–700 mm/a). The projected more frequent drought spells, especially in southern Finland, indicate that the risk of wild fires may increase substantially. The main remaining uncertainties are related to the seasonal distribution of precipitation. Warmer temperatures in spring and early summer may lead to earlier melting of snow and drying of the soil in summer (Zackrisson 1977). A temperature increase alone (assuming no change in precipitation) of 3–5°C in summer (June–August) has been projected to increase the fire area in western Europe 15 to 50 times (Suffling 1992).

Insects: Pest insects are of considerable relevance in the boreal domain (e.g. Logan et al. 2003). Climate change affects insect outbreaks through several mechanisms, by altering (Evans et al. 2002): (i) survival and reproduction of the insects, (ii) natural enemies of the pests, (iii) nutrient content of the host trees, (iv) vigour and defence capabilities of the host trees, and (v) phenological synchrony of the pest and host trees (cf. Fischlin et al. 2007, section 4.4.5).

The northward expansion of several insect species and forest pests is likely to occur (Battisti 2004). However, the net impact of climate change on pests is complex to predict owing to interactions among plant defence mechanisms, food quality (Niemelä et al. 2001) including C:N ratio and effects of N-deposition on host plants, fire, altered ranges of forest species including enemies, feedbacks, weather and other factors (Williams et al. 2000). The complexity among these interactions results in a high degree of uncertainty with respect to future damage from outbreaks of endemic invasive insect pests (Fleming and Candau 1998, Fischlin et al. 2007). However, forest pests generally are likely to increase in frequency and intensity under climate change, particularly in the margins of the host tree species (Harrington et al. 2001, Fischlin et al. 2007, Ward and Masters 2007, see also Chapter 2).

The winter minimum temperature is the most important factor limiting pest distribution in the north. A warmer climate could provoke increases of outbreaks towards the north and accelerate the intensity and frequency of population peaks, although parasitoids and other natural enemies may cause higher mortality of larvae in the summer (Niemelä et al. 2001). The overall effect of this is not only poorly understood, but can hardly be generalized. However, a drier and warmer summer is favourable to the life strategy of many pests, and since pest insects multiply easily, they have in general a large potential for genetic adaptation to new environments, including their ability to defy control.

Although it is unlikely that insect pest species would have lower short-term success in a changing climate, Fleming and Candau (1998) suggested that certain feedbacks such as loss of host trees may actually reduce outbreaks, at least regionally. Nevertheless, it is known from many pests that they are very likely to have higher success: the European spruce bark beetle *Ips typographus* is one of them, the occurrence of which is typically related to the prevailing temperature conditions (Parry 2000). In spring the flight of *I. typhographus* occurs when daily mean temperatures exceed 18°C. The increasing spring and summer temperatures may increase the number of generations and the success of this species throughout Europe (e.g. Schlyter et al. 2006, Dobbertin et al. 2007). Similarly, the populations of *Neodiprion sertifer*, *Diprion pini* and *Panolis flammea* may grow due to temperature elevation by 2–3°C during the summer (cf. Virtanen 1996). Temperature elevation may also expand the occurrence of *Lymantria monacha* far up above the 60th latitude over Scandinavia. Currently, this insect damages Norway spruce mainly in central and southern Europe (Bejer 1988), wherever the mean temperature of July exceeds 16°C and the mean temperature of September exceeds 10.5°C (Parry 2000). In western Canada, recent climate change has been linked to the loss of millions of hectares of lodgepole pine (*Pinus contorta*) forest due to the mountain pine beetle (*Dendroctonus ponderosae*) (Logan et al. 2003, Carroll et al. 2004, Fischlin et al. 2007, Kurz et al. 2008).

Pathogens: High summer temperature combined with drought may damp down the epidemics of damaging fungi, but they may flourish in cool rainy summers. On the other hand, higher winter temperatures may enhance epidemics of damaging fungi like *Gremmenniella abietina* and *Lophodermella sulcigena*. The frequency of root rot induced by *Heterobasidion annosum* may also be larger, if the autumn, winter and spring temperatures are higher and the duration of frozen soil is shorter. In northern Europe, especially, climate change seems to enhance the occurrence of root rot with an increase in loss of timber and forest productivity (Parry 2000).

Alien invasive species: Alien invasive species are becoming a problem globally, and climate change will interact to increase the likelihood of their success (cf. Fischlin et al. 2007, section 4.4.11 [p. 218], Ward and Masters 2007). A good example of new organisms with large potential to damage trees is *Bursaphalencus xylophilus* nematode originating from North America. This pine nematode is quite easily transported in fresh timber, but its success is quite closely related to temperature. Until now, low summer temperatures and short growing seasons are effectively limiting the success of this species out-

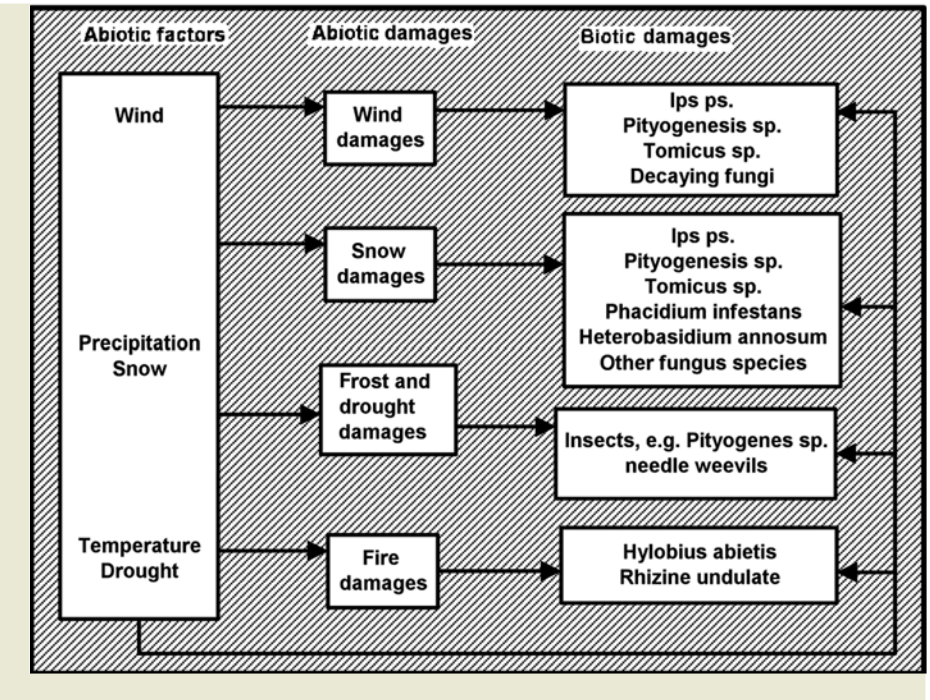

Figure 3.10 Weather and climate not only directly impact trees and trigger outbreaks of many populations of damaging insects and fungi but may also indirectly cause additional damage through weakening host trees and allowing infestations to develop further, thus exacerbating the damage (Parry 2000).

side northern Europe, even though it has frequently occurred in imported timber elsewhere within the boreal domain (see also Chapter 2).

Interaction between abiotic and biotic disturbances: Climate change may increase the mortality of trees and increase the risk of abiotic and biotic damage in boreal forests. Mortality of trees is endogenously related to the growth and life cycle of trees or exogenously related to the abiotic (frost, wind, snow, fire) and biotic (insect and fungal pests) factors.

Whenever climate change increases the growth of trees, endogenous mortality is expected to be larger due to a more rapid life cycle. An increased endogenous mortality may also increase the risk of exogenous mortality, since major outbreaks of many damaging insects and fungi are closely related to the presence of dead or dying trees or trees weakened by abiotic damage (Figure 3.10). Trees broken and uprooted by wind and snow provide more breeding material for bark beetles and increase the susceptibility of the entire stand to further attacks, which may even lead to an epidemic outbreak (Christiansen and Bakke 1988). Subsequent high summer temperatures and concomitant possible drought may weaken tree growth, while further increasing the growth of insect populations through enhanced physiological activity and more generations during the growing season (e.g. Wermelinger and Seifert 1999, Schlyter et al. 2006).

Herbivores: Currently, large herbivores like moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) are one of most important factors defining species composition of young forests in northern Europe and central-eastern North America. Current and future distribution of large herbivores is affected by high temperature in summer and the depth and seasonal distribution of snow. Thinner snow cover makes it easier for moose to move in winter. However, moose become thermally stressed by temperatures above –5°C in winter and above 14°C in summer, and deer are stressed below 5°C in winter (Schwartz and Renecker 2007, see also Chapter 2). Furthermore, composition and palatability of tree species also influence the success of mammalian herbivores. For instance, elevated levels of CO_2 can decrease the palatability of birch (*Betula pendula*) for hare (*Lepus timidus*) (Mattson et al. 2004).

3.4.5 Future Opportunities and Services at Risk

Timber: For North America, IPCC (Denman et al. 2007, Fischlin et al. 2007) reports a slow increase (1% per decade) in forest growth in the boreal regions, where the growth is limited by the low summer temperature and short growing season. The increase is most probably in the ecotone between the boreal and tundra vegetation, indicating the northward shift of boreal forests. On the other hand, the forest growth may be reduced locally at water-limited sites due to increasing drought episodes, with a consequent northward shift of boreal forests. The same trends are expected for the Siberian boreal forests. Based on the expected changes in the primary productivity, a slight increase in the potential timber harvest may be possible in the boreal forests of North America, Russia and the Nordic countries.

Carbon: Climate change can affect high-latitude carbon cycling through changes in the regeneration and growth of trees and changes in decomposition of organic matter in the forest floor and mineral soil. These changes are caused by changes in tree-species composition and enhanced decay due to elevated temperatures. Both processes are further controlled by fire- and wind-induced disturbances with impacts on the regeneration, growth and decay. The increase in March and April temperatures in high-latitude boreal forests results in earlier snow melt and lengthens the growing season, which, along with higher summer temperatures and higher atmospheric $CO_{2,}$ should enhance the total carbon uptake and, thus, an increase in summer carbon gain, balancing the increasing winter respiration in the ecosystem (decomposition, respiration of living organisms).

Whenever climate change increases tree growth, one may expect enhanced carbon sequestration in trees and soils. This applies especially to the northern and middle boreal forests, where the growth and litter yield will increase more rapidly than the decomposition of soil organic matter. However, the mean total amount of carbon will probably remain smaller in the north than in the south, even though the productivity of forests in the south is likely to decrease in many instances. Over Finland, the increase in the total amount of sequestered carbon in upland sites may be close to 30% higher than today (Kellomäki et al. 2008, Box 3.1).

Fire releases carbon to the atmosphere but it also converts a small fraction of decomposable plant material into stable charcoal. In old-growth forests, fire reverses forest succession and creates younger forests with higher growth rates, but it alters also the soil's thermal and moisture conditions, affecting decomposition and the availability of soil nutrients (Kasischke et al. 1995). The effects of climate change on long-term carbon sequestration depend greatly on the characteristics of the fire regimes. Fire has a highly variable direct and long-term effect on carbon losses, which depend on fire intensity and extent. Both depend on soil moisture and the quantity and quality of litter and other organic material on the soil surface. Given recent observations and model projections (cf. Fischlin et al. 2007, p. 228), an increase in fire episodes throughout the boreal forests is very likely and is expected to substantially increase carbon emissions from the boreal domain. Direct and indirect fire-generated carbon emissions from boreal forests may even exceed 20% of the global emissions from all biomass burning (Conard and Ivanova 1997).

Epidemic insect outbreaks can release significant amounts of carbon to the atmosphere. Pest insects are also of high relevance in the boreal domain and affect an area about 50 times larger than fire with a significantly larger economic impact (e.g. Logan et al. 2003), as the following example demonstrates. Warming at the end of the last century has allowed the build-up of significant outbreaks of the mountain pine beetle (*Dendroctonus ponderosae*), allowing the pest to invade new territories. Thanks to colder winter temperatures in the first half of the 20th century, this species used to cause no outbreaks in western Canada (Carroll et al. 2004). The recent, unprecedented outbreaks were estimated to continue to release up to 2020 large amounts of carbon, i.e. 270 MtC, turning those forests from a small sink into a large source (Kurz et al. 2008).

Biodiversity: The ecotone between boreal forest and tundra is a prominent feature of the northern boreal region, with a high value for biodiversity. In general, the higher productivity of boreal forests may increase species-richness and biodiversity in the long term, especially in the northern parts of the boreal zone. On the other hand, the change in tree-species composition alters substantially the properties of forest habitats. This may imply reduced success for true taiga species, which may be partly replaced by more southern species even in the central and northern parts of the boreal zone. However, assuming current management, the amount of decaying wood may increase in a changing climate. This is due to the higher primary productivity and faster maturation of trees, which result in a shorter life span of trees and increase the mortality of trees that are not removed by felling. More dead wood may increase the success of many rare and endangered species that fully depend on decaying dead wood (Kellomäki et al. 2001).

Climate change will eventually expand the treeline communities northwards. However, the geographic ranges of certain species such as white spruce (*Picea glauca*) are not expected to shift uniformly. In Alaska and north-western Canada, northward advances may be slow in the dry central parts of the northern boreal forest, whereas improved growth conditions are expected in moister habitats. On the other hand, the large-scale death of white spruce forests due to more prevalent attacks of spruce bark beetle (*Dendroctonus rufipennis*) will probably reduce the existing species richness temporarily, while giving space for more southern species to invade. At the southern tundra boundary in North America, spruce may be replaced by aspen (*Populus tremuloides*) (Hogg and Hurdle 1995). The poor success of Norway spruce

(*Picea abies*) in the southern ecotone between the boreal and temperate vegetation zones in northern Europe is identified in several model exercises (Kellomäki et al. 2008). All these processes are likely to reduce the role of taiga species in these locations, while it is highly uncertain precisely which species may replace them or at what time.

3.4.6 Key Vulnerabilities

Boreal forests from the Northern Hemisphere provide key provisioning services. Although primary productivity is still expected to increase, in general, for climate-change scenarios from the clusters *growth* and *stable* in the boreal domain and, in particular, in its northern forests, the same climate change is also likely to have negative impacts; these may particularly affect the currently more productive southern forests and all boreal forests through fire (e.g. Stocks et al. 2002, Fischlin et al. 2007) and insect incidences (e.g. Fischlin et al. 2007, Kurz et al. 2008). Both effects appear to have the potential for being significant for key services, but the overall balance can only be assessed if quantitative estimates become more reliable. This corroborates previous IPCC assessments pointing at the wide swings in provisioning services of boreal forests (Solomon 1996). On the other hand relatively well-understood temporal characteristics of these responses indicate high risks for overall negative effects to occur, more likely than not from now on and during a possibly century-long transient period.

3.5 Temperate Domain

3.5.1 Types of Temperate Forest

Temperate forests are found at mid-latitudes (~30° and <50° N and S, respectively) and cover an area of about 10.4 Mkm^2 (Fischlin et al. 2007). They can be grouped into warm deciduous or summergreen, and broad-leaved or conifer south-temperate forests (Olson et al. 1983) or, alternatively, into the ecological zones: oceanic, continental and mountain temperate forests (FAO 2001b, FAO 2006). Annual mean temperatures are below 17°C but above 6°C, annual precipitation is at least 500 mm and there is a markedly cool winter period (Walter 1979). Within the temperate zone one finds steep climatic gradients of precipitation and temperature, in particular with changes in altitude, and from oceanic to continental areas, all resulting in a considerable diversity among temperate forest types. The biome occurs primarily in the Northern Hemisphere, and in the south it is limited to areas of Chile, Argentina, New Zealand, South Africa and eastern Australia. Canada, the USA and Russia together hold 70% of temperate forests. China also has extensive areas of temperate forests, although most of these are second-growth and plantations. Several of the smaller areas maintain high levels of endemic biodiversity in part owing to their long-term isolation. They are important hotspots, including some in South Africa, New Zealand and Australia. Temperate forests are dominated by broad-leaf species with smaller amounts of evergreen broad-leaf and needle-leaf species (Melillo et al. 1993).

Tree species diversity is highest in the Asian temperate zone, where >900 woody species occur, nearly four times the North American species richness for this biome (Ohsawa 1995). Common species include the oaks (*Quercus*), eucalypts (*Eucalyptus*), acacias (*Acacia*), beeches (*Fagus* and *Nothofagus*), pines (*Pinus*) and birches (*Betula*). Temperate rainforests occur in several areas including western North America, Australia, New Zealand, Chile, South Africa and south-eastern Asia. The three main natural disturbances in temperate forests are wind, fire and herbivory (Frelich 2002). These vary in importance depending on rainfall and temperature (cool v. warm, and forest composition is mediated through the long-term interaction among these disturbance types (Kira 1991). Climate change is predicted to alter all these disturbances (Meehl et al. 2007), leading to uncertainty in future forest species composition. Changes as a result of climate-mediated herbivory are discussed in Chapter 2, but these are considerably altered by anthropogenic influences such as land-use change, introduction of invasive alien species, and predator control.

Annual net primary productivity of natural northern temperate forests is 900–1000 g/m^2 while more southerly stands can produce up to 1400 g/m^2 (Lieth and Whittaker 1975). Soil carbon ranges from 1 to >4 kg/m^2, depending on forest type in North America (Finzi et al. 1998) but up to 7.7 kg/m^2 in central Europe (Balesdent et al. 1993). The primary productivity of most temperate forest ecosystems may be limited by the availability of nitrogen, except where moisture may limit the system (Aber 1992, Rastetter et al. 2005). However, the addition of nitrogen increases productivity only to a certain extent, limited later by other minerals such as aluminium or as a result of elevated pH (e.g. Schulze 1989). Furthermore the C:N ratio is important for the rate at which carbon may be sequestered; hence there is debate over the functionality of nitrogen fertilization (e.g. Nadelhoffer et al. 1999, Martin et al. 2001). Recent evidence suggests, however, that in temperate forests, after the effects of disturbance have been accounted for, net carbon sequestration is mostly driven by nitrogen deposition, coming mostly from anthropogenic activities, and that this relationship is positive over a range of nitrogen deposition rates (Magnani et al. 2007). However, global warming seems to be reducing the total carbon uptake in temperate forests through losses from the soil in autumn, offsetting spring gains, which suggests that temperate forests may become in the future relatively poor carbon sinks if warming continues (Piao et al. 2008). Altered nitrogen and carbon levels will have effects on species composition of these forests (Parry 2000). Furthermore, while forest age is also a factor in carbon cycling, Luysseart et al. (2008) suggested that old-growth forests continue to sequester carbon at a high rate of 1.36 + 0.5 GtC/a. In North America, the recent invasion by native and exotic earthworms is altering forest function and the C:N ratios (e.g. Bohlen et al. 2004). This northward expansion will be enhanced by climate change and alter ecosystem properties, including the rate of carbon loss.

Owing to the large number of people living near temperate forests or in temperate forested lands, the entire range of goods and services from these forests is important. However, because of their mid-latitude position in a climate highly favourable to humans, temperate forests are, historically and pre-historically, the most extensively altered forests among all forest biomes. In Europe, temperate forests cover 160 million ha, which represents <50% of the original forest cover, and in both Europe and the USA, less than 1% of these deciduous forests are original primary forests (Reich and Frelich 2002). Furthermore, high levels of pollutants have entered many temperate forest areas since the beginning of the Industrial Revolution. Many of the major factors that influence these forests are due to human activities, including land-use and landscape fragmentation, pollution, soil nutrients and chemistry, fire suppression, alteration to herbivore populations, species loss, alien invasive species, and now climate change (Reich and Frelich 2002).

3.5.2 Main Services Provided

Of particular concern in the temperate domain is the loss of provisioning and cultural services, partly due to the high primary productivity of temperate forests at sites with high water availability and high nutrient levels, and to their proximity to densely populated areas in industrialized countries. In the latter areas, temperate forests increasingly provide many socio-economic and cultural services and often serve conservation goals directly or indirectly. More and more tourism, leisure and sports activities take place in those forests. The many species they harbour get under considerable anthropogenic pressure due to intensification of agricultural practices and urbanization. Only recently, in particular in western Europe, a reverse of some of these trends could be observed: Pressure on forests lessened due to intensification of agriculture (e.g. Rounsevell et al. 2006).

Timber: Northern Hemisphere temperate forests are important sources of round wood and pulpwood, with the types of products varying greatly depending on the region and forest types. Wood produced by Northern Hemisphere forests was largely responsible for the lumber supply of the rapid post-industrialization housing and urban growth of Western civilizations. Now, the region's timber production is increasingly being met from plantations (Easterling et al. 2007, Bosworth et al. 2008) and round-wood production for these forests is projected to increase some 25% over the next 20 years (Turner et al. 2006).

Carbon: Northern Hemisphere temperate forests are important sinks for atmospheric CO_2 (Goodale et al. 2002). However, estimates of the magnitude and distributions of this sink vary greatly and depend on temperature, nitrogen fertilization, fire, invasive species, age of the forest and levels of pollution. Temperate forest regions in the highly productive forests of western Europe (Liski et al. 2002), eastern USA (Birdsey et al. 2006) and east Asia (Saigusa et al. 2008) are known to be robust carbon sinks, although increased temperature may reduce this effect through loss of carbon from soils (Piao et al. 2008). Current carbon sink strength estimates for northern Caucasian forests, which were influenced by recent trends of forest exploitation, were found to be presently three times smaller than the figure estimated for 1970–1990 and five times smaller compared to the period 1950–1970 (Bakaeva and Zamolodchikov 2008). Less certain are the sink strengths of old-growth temperate forests (Pregitzer and Euskirchen 2004, Luyssaert et al. 2008), which, until recently, were thought not to be as strong sinks as younger, more rapidly growing forests. Weaker carbon sinks or even carbon losses are also seen for temperate forests in areas prone to periodic drought, such as the western USA, southern Europe, many parts of Australia and the southern Russian Far East (Moiseev and Alyabina 2007).

Non-timber products and uses: The world's temperate forests are responsible for a host of regionally dependent non-timber forest products and services. Firewood and indigenous people's speciality products such as botanical and medicinal products, mushrooms, fruits and nuts, and crafts materials are all supplied from these forests. Fuelwood is an important product from temperate forests, which provide roughly 10% of the global fuelwood harvest (FAOSTAT 2003). In addition, these forests protect water quality and quantity by harbouring water reservoirs for many of the world's major cities, provide wildlife habitat for game birds and animals, and are important refuges of biologically diverse fauna and flora. Increasingly, the world's temperate forests are utilized for recreational activities such as hiking, cross-country skiing and camping.

3.5.3 Current Opportunities and Vulnerabilities

Current climatic trends (e.g. Trenberth et al. 2007) indicate an increase in primary productivity in all humid regions, particularly the mesic regions and to a lesser degree the oceanic regions – due to slower warming rates. These forests are therefore expected to continue the strengthening of the carbon sequestration regulating services in the near future (at least roughly two decades, e.g. Fischlin et al. 2007, p. 222, Fig. 4.2) and do currently mitigate climate change. However, this is challenged by other authors as highly dependent on temperature, nitrogen and other mineral levels (e.g. Hungate et al. 2003, comprehensively reviewed by Fischlin et al. 2007 [section 4.4.1], Magnani et al. 2007, Piao et al. 2008). Moreover, this increased productivity for the near future is expected to sustain provisioning services, notably lumber production in the short- and mid-term (Easterling et al. 2007, IPCC 2007c).

However, primary productivity is expected to decrease as the drier regions of the temperate domain covering semi-arid to sub-humic climates in regions adjacent to the subtropical domain continue to experience more drought spells and, in general, a decrease in summer precipitation. Moreover, increased fire frequencies and areas involved and/or more intense fire events are expected as a result. Drought as well as fires will also lead to substantive carbon releases. For instance, in summer 2003 drought impacts on vegetation (Gobron et al. 2005, Lobo and Maisongrande 2006) reduced gross primary production in Europe by 30%. Respiration was also reduced, but to a lesser degree. The overall effect was a net carbon loss of 0.5 PgC/a (Ciais et al. 2005). Record-breaking incidences of wildfires in terms of spatial extent were observed throughout Europe in 2003 (Barbosa et al. 2003), with roughly 650 000 ha of forest burnt across the Continent (De Bono et al. 2004). Finally, as warming continues to accelerate according to the scenarios in the clusters *fast growth* or *growth* (IPCC 2007d [p. 45, section 3.2.1], IPCC 2007c [p. 12–13]), many forests in the temperate domain currently showing increasing productivity are likely to switch into a mode where production decreases as their climate moves toward sub-humic or even drier conditions, leading at some unknown point in the future to an overall productivity loss in the temperate domain (Lucht et al. 2006, Schaphoff et al. 2006, Scholze et al. 2006, Canadell et al. 2007, Fischlin et al. 2007, Raupach et al. 2007).

3.5.4 Projected Future Impacts and Autonomous Adaptation

Forest productivity has been increasing in two major temperate forest regions: eastern North America (Soule and Knapp 2006, Field et al. 2007b), and western Europe (Carrer and Urbinati 2006). This is thought to be from increasing CO_2 in the atmosphere (Field et al. 2007b), anthropogenic nitrogen deposition (Hyvönen et al. 2007, Magnani et al. 2007), warming temperatures (Marshall et al. 2008), and associated longer growing seasons (Chmielewski and Rötzer 2001, Parmesan 2006). Most models predict continuing trends of modestly increasing forest productivity in eastern North America and western Europe over this century (Alcamo et al. 2007, Field et al. 2007b, Alo and Wang 2008). Regional declines in forest productivity have also been seen in some areas of temperate forests due primarily to water scarcity as a result of recent droughts in Australia (Pitman et al. 2007), western North America (Breshears et al. 2005, Grant et al. 2006, Cook et al. 2007), and the European heat wave of 2003 (Schär et al. 2004, Ciais et al. 2005). There is a high likelihood of decreased summer precipitation and there is a high probability of an increased occurrence of heat waves over the next century (Alcamo et al. 2007, Field et al. 2007b) so that occurrences of drought will become more frequent, particularly at the southern end of the temperate forests from the Northern Hemisphere and in Australia. Thus, these events are likely to continue to have a negative impact on forest productivity in those areas.

Projections for the time near the end of the next century generally suggest decreasing growth and a reduction in primary productivity enhancement as temperatures warm, CO_2 saturation is reached for photosynthetic enhancement, and reduced summer precipitation all interact to decrease temperate zone primary productivity (for lodgepole pine Rehfeldt et al. 2001, Lucht et al. 2006, Scholze et al. 2006, Alo and Wang 2008). What is further contributing to decreased long-term primary productivity in some regions of temperate forests under climate change is the projected increased occurrence of forest pests, particularly in drought-stressed regions (Williams et al. 2000, Williams and Liebhold 2002), prolonging current trends of recent climate change-induced pest infestations (e.g. Logan and Powell 2001, Tran et al. 2007, Friedenberg et al. 2008).

Timber: Sustainable forest management is becoming more common in productive temperate forests, increasing the likelihood of sustainable management in the face of climate change. Temperate forest plantations are increasing and these are expected to provide an ever-increasing percentage of the roundwood products over the next century (Sedjo 1992, Birdsey et al. 2006). Timber volumes are likely to follow similar trends to those of primary productivity as discussed above.

Carbon: Climate change resulting from the enhanced greenhouse effect, together with the direct effects of increasing amounts of atmospheric CO_2 and increasing nitrogen deposition, are all expected to produce changes in the cycling of carbon in the temperate forest ecosystem (Morales et al. 2007). Increases in carbon sink strength are expected in some productive regions under intensive forest management such as central western Europe (Morales et al. 2007), while decreasing sink strength is projected for temperate forest areas facing increasing drought occurrence, such as southern western Europe (Morales et al. 2007), the southern part of the Russian Plain (Golubyatnikov and Denisenko 2001, Kolomyts 2006) and in ageing eastern North American forests (Birdsey et al. 2006).

Biodiversity: One of the most dramatic predictions of temperate forest model projections is the substantial range shifts which are expected to occur at the northern and southern borders of temperate forest (Iverson and Prasad 2001, Parmesan 2006, Fischlin et al. 2007, Gessler et al. 2007) and at higher levels on mountains (Breshears et al. 2008, Kelly and Goulden 2008). The ranges of northern temperate forests are predicted to extend into the boreal forest range in the north and upward on mountains (Iverson and Prasad 2001, Ohlemüller et al. 2006, Fischlin et al. 2007, Golubyatnikov and Denisenko 2007, Figure 4.3, p. 238). The distribution of temperate broad-leaved tree species is typically limited by low winter temperatures (Perry et al. 2008). Since the latter are projected to rise more rapidly than summer temperatures in Europe and North America (Christensen et al. 2007, sections 11.3, 11.5), temperate broad-leaved tree species may profit and invade currently boreal areas more rapidly than other temperate species. The area of temperate forests is projected to decrease at boundaries with the forest-steppe biome (Kolomyts 2006, Golubyatnikov and Denisenko 2007).

A major concern for biodiversity is that some species and certainly many populations within species may not be able to migrate quickly enough to find their suitable temperature niches due to the unprecedented rapidness of global warming (Fischlin et al. 2007). The few studies that have shown evidence of range shifts have reflected the limited capacity to disperse (Davis et al. 1986, Davis 1989). The main form of forest tree migration is via seed dispersal. However, only a few temperate-zone tree species, such as trembling aspen, have those very small seeds displayed in ultra-light pubescence so that they are readily dispersed by wind over long distances. However, global warming is expected to expatriate even trembling aspen from the north-eastern US temperate forests (Iverson and Prasad 2001). On the other hand, recent modelling studies incorporating population (O'Neill et al. 2008) and provenance variation (Reich and Oleksyn 2008) suggest that there is more plasticity than previously thought for response of temperate-forest trees to global warming in some regions.

Drought: Models suggest that the greatest climate-change threat to temperate forest ecosystems is reduced summer precipitation, leading to increased frequency and severity of drought (Christensen et al. 2007, Fischlin et al. 2007, IPCC 2007c, Meehl et al. 2007, Schneider et al. 2007, Chapter 3.2). This will probably be most prominent in temperate forest regions that have already been characterized as prone to drought stress, such as the western USA, northern China, southern Europe and the Mediterranean, and Australia (Photo 3.1). However, drought may also have widespread impacts on other northern temperate forests, particularly in limiting growth (Ciais et al. 2005, Leal et al. 2008) and triggering dieback and decline (Breshears et al. 2005) for species or populations within species near the southern borders of their range, such as paper birch in the Lake States of the USA (Jones et al. 1993), Austrian pine in the Alps (Leal et al. 2008), and European beech in southern Europe (Gessler et al. 2007).

Some effects of drought on primary productivity may be offset by near-term increases in water-use efficiency in a CO_2-enriched atmosphere (Aber et al. 2001) or by soil fertility (Hanson and Weltzin 2000). In the long term, however, productivity of temperate forests constrained by drought in the next century will be reduced, and declines and dieback episodes will occur more commonly under global warming (Breda et al. 2006). Drought during canopy development can have a long-lasting impact on carbon balance (Noormets et al. 2008). Drought-stricken forests are also more susceptible to opportunistic pests and fire (e.g. Hanson and Weltzin 2000). Together, these related effects can potentially change large areas of temperate forest ecosystems from carbon sinks to sources.

Fire: Fire is expected to be an ever increasing problem over the next century in the temperate forest as summer precipitation decreases, temperatures increase and drying conditions predominate, particularly in the Australian temperate forests (Pitman et al. 2007), as well as those in western North America (Breda et al. 2006, Cook et al. 2007), southern Europe (Ohlemüller et al. 2006), and northern Asia (Groisman et al. 2007).

Pests: Warming temperatures in temperate forests and increased occurrence of water stress are both likely to have important consequences for pest outbreaks. Warmer temperatures will mean more rapid growth of insects, shorter generation times for insects, and movement of temperature-sensitive insects into more poleward regions (Marshall et al. 2008).


John Innes

Photo 3.1 Dieback of *Eucalyptus gunnii* in the central Highlands of Tasmania, Australia. While the exact sequence of events leading to the tree mortality is uncertain, drought has been strongly implicated.

Unprecedented mountain pine beetle outbreaks have already been documented in northern British Columbia, Canada, related to global warming (Kurz et al. 2008), birch defoliations are extending farther north into Fennoscandia (Jepsen et al. 2008) than previously, and the highly damaging processionary moth is expanding northward and into the mountains from its traditional Mediterranean distribution (Battisti et al. 2005, Battisti et al. 2006).

Furthermore, warmer temperatures tend to remove bioclimatic barriers to the spread of alien pests, pathogens and plants. These alien invasives can quickly and permanently alter the composition of forests: for example, the emerald ash borer and hemlock woolly adelgid in eastern North America, sirex woodwasp in the southern hemisphere, pinewood nematode in Asia and western Europe, and sudden oak death in western North America and Europe (Dwinell 1997, Bergot et al. 2004, Butin et al. 2005, Hurley et al. 2007, Anulewicz et al. 2008). Some other insects and diseases are expected to increase in areas impacted by tropospheric O_3 (Chakraborty et al. 2008) or drought (Desprez-Loustau et al. 2006, Desprez-Loustau et al. 2007).

Under all scenarios of climate change (this report, sub-chapter 3.2.4), it seems likely that biological disturbance from established pests and pathogens will tend to increase on the warming poleward margins of temperate forests. Change will also occur along any other margins where water availability for trees is going either up or down. Furthermore, increasing commerce, in combination with modest climatic change, is very likely to produce additional biological invasions that will lead to further changes (generally increases) in forest disturbance. On the plus side, climate change will probably produce net decreases in pestilence in some regions (perhaps generally in subequatorial margins of temperate forests), and primary productivity will tend to go up overall, meaning that more losses to pests and pathogens can potentially be tolerated without losses in ecosystem services. However, even if the average level of pestilence remains the same (but probabilities change among regions), there would still be a tendency for transient reductions in the extent of mature forest because disturbance reduces a mature forest quickly while new mature forests can arise only slowly.

Other Disturbances: While fire, pest outbreaks and extreme weather events are well known to shape ecosystems (Field et al. 2007a) the contribution of land-use change is a very large driver of the temperate forest carbon budget, both in the Northern (Breshears and Allen 2002, Easterling and Apps 2005, Albani et al. 2006) and Southern (Wilson et al. 2005) Hemispheres. For example, in the northern temperate zone, increasing carbon stocks were seen in the USA during the past century as forests were regrown after extensive early logging, and as increas-

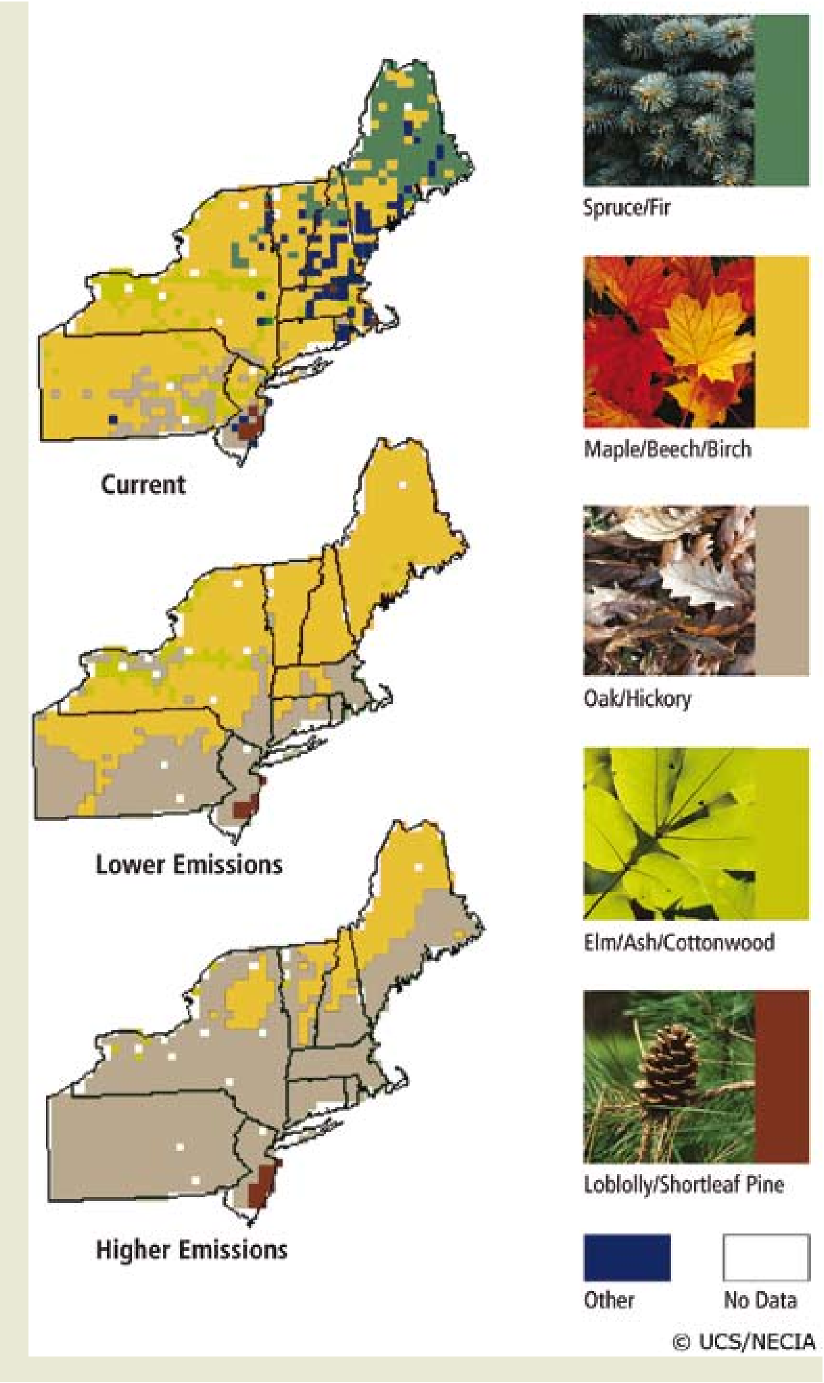

Figure 3.11 Projected distribution of forest types by major species groups of temperate forests in north-eastern USA from Frumhoff et al. (2007, Reprinted with permission of the Union of Concerned Scientists). Lower emissions correspond to a scenario from cluster *stable*, higher emissions to one from cluster *growth*.

ing amounts of marginal farm land were returned to forests (Caspersen et al. 2000, Birdsey et al. 2006). Without substantial carbon management practices such as the development of extensive energy plantations, the rate of carbon sequestration for these previously disturbed forests is expected to diminish over the next century as these forests mature (Albani et al. 2006, Birdsey et al. 2006).

Conversion of large areas of Southern Hemisphere temperate forests to exotic species plantations continues to be a concern for the next century (Wilson et al. 2005). Among the concerns regarding conversion in biologically and ecologically diverse areas is that habitat fragmentation will exacerbate climate-change effects related to species migrations with global warming (Honnay et al. 2002).

Air Pollution: Most industrialized and some of the largest urban areas are within the temperate domain. Consequently, temperate forests are particularly exposed to air pollution. Total deposition of nitrogen to temperate forests, in wet or dry, and oxidized or reduced form, is between 1 and 100 kg/ha/a (Hyvönen et al. 2007). The larger amounts are from industrialized regions such as the north-eastern USA and Central Europe. While this nitrogen has generally been thought to have a positive effect by stimulating primary productivity, as most forests occur on N-limited soils (Lebauer and Treseder 2008), there is a great deal of uncertainty as to whether detrimental effects of nitrogen saturation will eventually appear (Aber et al. 1998). A lively debate has started over the role of nitrogen deposition in the future carbon sequestration potential of temperate forests (Högberg 2007, Magnani et al. 2007, Sutton et al. 2008).

A second air pollutant projected to increase in the next century over large areas of temperate forests that are downwind of major metropolitan areas, is tropospheric ozone (Meehl et al. 2007, section 10.4.3). Tropospheric O_3 is a secondary pollutant that is generated from nitrogen oxides reacting with volatile organic compounds in the presence of sunlight. It is a highly reactive pollutant that can reduce the growth and carbon sequestration capacity of sensitive species (Karnosky et al. 2005, McLaughlin et al. 2007). Ozone is generally increased during extreme heat events such as the European heat wave of 2003 (Guerova and Jones 2007, Solberg et al. 2008), leading scientists to predict increasing ozone over large portions of the temperate forest in the next century as global warming continues (Fowler et al. 1999, Vautard et al. 2007, Andreani-Aksoyoglu et al. 2008).

As with all biomes, forest types and tree species are projected to change their distributions with climate warming. For example, in the north-eastern USA and south-eastern Canada, tree species are predicted to range northwards by up to 700 km, and certain forest types that occur unusually far south owing to montane conditions, are expected to disappear (Figure 3.11, Price and Scott 2006, Frumhoff et al. 2007). Similarly in Europe, reduced growth is already seen in southern-growing *Fagus sylvatica* (Jump et al. 2006). All authors agree that there is a high degree of uncertainty surrounding the relative species composition of future temperate forests, but that the area will remain well forested.

3.5.5 Future Opportunities and Services at Risk

Globally, temperate forests are among the world's most stable forests. As such, they are less likely to suffer severe consequences from climate change than some other forest types. However, there are rather dramatic regional risks that can have large impacts on temperate forests. Among these, the most widespread are related to projected decreases in summer rain as global warming continues. Droughts over expanded regions and with greater intensity and frequency are predicted for large areas of temperate forests over the next century. These droughts will probably lead to more frequent fires and will also predispose large areas of forests to opportunistic pests and pathogens such as bark beetles, Armillaria and wilt diseases. Regions of increasing precipitation may experience decreased risks from these pests and pathogens but increased risks from others.

In many temperate forests windthrow is the most important natural disturbance (e.g. Thürig et al. 2005). Since extra-tropical stormtracks are projected to move poleward (IPCC 2007d, p. 46) frequency and even intensity may increase and cause major forest disturbances. The fact that current climate models underestimate recent observations (IPCC 2007b, p. 10) is of particular relevance in a context of managing climate risks for temperate forests.

Finally, sensitivity to increasing air pollution loads, particularly nitrogen deposition and tropospheric O_3, will impact large areas of the northern temperate forest over the next century. Humans will also increasingly impact temperate forests as they cause land-use change and habitat fragmentation, which will interact with the above-mentioned risks to exacerbate biodiversity issues relating to species migration and wildlife habitat management.

3.5.6 Key Vulnerabilities

In some productive temperate regions, moderate climate change is expected to lead to improvements in timber production as well as regulating services, such as increases in carbon-sink strength, in particular under intensive forest management. However, towards the end of this century and beyond, in particular for scenarios from clusters *growth* and *fast growth*, reductions in primary productivity are projected due to above optimum temperatures, declining water availability during the growing season, and CO_2 saturation effects. Forests that are already prone to drought stress such as the western USA, northern China, southern Europe and the Mediterranean, and Australia, are projected to be affected not only by reduced summer precipitation but also by increased frequency and severity of drought and fires, with all the concomitant negative effects. In the temperate domain, air pollution is expected to interact with climate change; while the fertilization effects from nitrogen deposition are still highly uncertain, pollutants such as O_3 are known to diminish primary productivity, impacting provisioning as well as regulating services. Biological disturbances from established pests and pathogens will tend to increase on the warming poleward margins of temperate forests. Similar effects are expected along any other margins where water availability for trees is diminished. While intensification of agriculture may lead in some areas to a decrease of pressures on vegetation and wildlife in forested or woodland areas serving often as refuges, the current trends of habitat fragmentation and impoverishment of the landscape are expected to continue, including increasing opportunities for invasive alien species. This is likely to increase the many threats to biodiversity in the temperate domain, exacerbating the extinction risks climate change is causing for many species inhabiting the temperate domain.

3.6 Subtropical Domain

3.6.1 Types of Subtropical Forests

Subtropical regions are generally found in mid-latitudes between 25° and 40° in the Southern and Northern hemispheres. As described and mapped by the Food and Agriculture Organization of the United Nations (FAO 2001b, 2001a), the subtropical domain includes areas with at least eight months of over 10°C mean monthly temperatures. Subtropical forest areas include regions of humid forest, dry forest, steppe or savanna woodlands and subtropical mountain systems.

The humid subtropical forests are found in regions that receive >1000 mm of annual rainfall, with no distinct dry season, and where mean annual temperatures range from about 15–21°C. The four main regions of humid forest include south-eastern USA, south-eastern areas of South America (including parts of southern Brazil, Uruguay and Argentina), southern China and eastern coastal Australia. There are also some smaller regions, such as in the south-eastern coastal part of South Africa. Though much of these regions have been cleared for agriculture, they often support well-developed native and plantation forests, including important commercial species. For example, *Pinus elliottii* var. *elliottii* is native to the subtropical humid region of the USA and is an important timber species. It is also grown as a plantation species in some of the other major subtropical humid regions. Similarly, *Eucalyptus grandis* is a significant native forest species in humid subtropical Australia, but it has proved useful as a plantation species in parts of the other major humid regions. However, the use of eucalypts in humid subtropical regions of the USA and China is limited by occasional frost events associated with cold air movements from the north.

Major regions of subtropical dry forest include Mediterranean areas (including parts of Spain, Italy, Greece, Turkey and North Africa), southern Chile, parts of California, coastal parts of the Western Cape region of South Africa and the south west of Western Australia. These regions have hot dry summers and humid mild winters, with annual rainfall in the 400–900 mm range. FAO (2001a) described typical forest types including: Maquis dominated by *Quercus ilex* in the Mediterranean region; chaparral in California; Chilean Matorral; Fynbos in the Cape Region of South Africa; and Eucalyptus forest in south-west Australia.

Subtropical steppe or savanna areas are semi-arid with long hot summers and generally short mild winters. They have an annual rainfall ranging from 250 mm to about 1000 mm where they transition into subtropical humid forest. Total annual evaporation generally exceeds precipitation. Grasslands dominate in lower rainfall areas with shrubs and trees becoming more common as rainfall increases. These areas include woodlands satisfying the forest definition of UNFCCC (2001). The regions include inland areas in eastern and western Australia, parts of Argentina and parts of south-central USA. There is a belt of subtropical steppe in northern Africa between the subtropical dry region and the Sahara desert, but the FAO classification does not recognize subtropical steppe regions in southern Africa as true forests.

Subtropical mountain systems in the FAO (2001a) classification are generally found at elevations of approximately 800–1000 m. The main subtropical mountain systems are found in parts of the Andes, central Mexico, south-western USA, the mountains of the Middle East, western parts of the Himalayas and the high veldt region of South Africa.

The CABI (2005) database lists 508 tree species from the northern latitudinal range and 238 species from southern latitudes, but not all listed species are endemic to the subtropical domain.

3.6.2 Main Services Provided

Humid subtropical forests have been extensively converted to timber plantations, mainly with exotic species, so their primary functions are wood production and water catchment. Major regions of the subtropical dry forests, especially the Mediterranean areas, are important for agriculture, soil conservation and tourism. One of the fastest-growing economic sectors in southern Africa is wildlife-based tourism, almost completely focused on subtropical forests as defined here. At about 9% of the regional GDP, tourism is already as important as the forestry and agricultural sectors in many countries (Scholes and Biggs 2004).

As described in CABI (2005) subtropical forests provide provisioning services such as 84 types of wood products and 19 non-wood products such as resins, oils and food. Subtropical forests provide 11 other land/environment services including regulating, supporting and cultural ecosystem services such as revegetation, land reclamation, soil improvement, soil conservation, erosion control, and aesthetic value.

3.6.3 Current Opportunities and Vulnerabilities

Opportunities: Subtropical species are partly already well adapted to warm and dry climates. There are many examples of species growing in managed forestry trials under considerably warmer conditions than those they experience within their natural distributions, i.e. their realized niche (discussed in Kirschbaum and Fischlin 1996, Box 1.3), or even in unmanaged forests if their dispersal is assisted by humans (Booth et al. 1988, Booth 2007). However, many subtropical species now exist in highly fragmented environments as islands of natural forest amongst oceans of agricultural land. Species at a particular location may not have access to new sites where they would be better adapted to the new climatic conditions. Less tolerant species may then decrease in abundance and hereby create for other, more tolerant resident species opportunities to become more abundant because of reduced competition. If well irrigated subtropical plantations can be highly productive, offering opportunities to contribute towards future demands for wood and other forest products.

Key vulnerabilities: Many species are vulnerable, since they have limited distributions and hence narrow climatic ranges, poor dispersal mechanisms, and are growing in areas of low relief. For example, an analysis using existing climatic ranges of 819 Eucalyptus species in the unmanaged dry subtropical zone, showed a large number of potentially vulnerable species (Hughes et al. 1996). This region is also relatively flat and eucalypt species have very poor dispersal mechanisms. While these species may indeed be at increased risk of extinction, it would be wrong to imply that a species will necessarily become extinct if climatic conditions become entirely different from those it currently experiences. For instance, species in mountainous areas may be able to colonize higher, cooler locations comparatively easily even if they have poor dispersal abilities. The lapse rate is typically about 0.5–0.7°C cooler per 100 m increase in elevation, a temperature change that corresponds to a poleward dispersal of ~100–200 km of flat land.

3.6.4 Projected Future Impacts and Autonomous Adaptation

Biodiversity: Though the impacts of climatic and atmospheric change on commercial forests may be significant, their vulnerability may generally not be very great. Potential impact is a function of exposure and sensitivity, while vulnerability is related to potential impact and adaptive capacity (Allen Consulting Group 2005). Commercially important species tend to be planted over wide geographic areas. Responses to disease problems have been demonstrated in the past, such as the replacement of susceptible eucalypt genotypes with resistant genotypes when guava rust became a problem in Brazil (Glen et al. 2007). Clearly, such adaptive capacity is most easily implemented in short-rotation species, so the longer the rotation the greater should be the concern with monitoring species performance under currently extreme conditions.

Productivity: Increasing CO_2 can affect tree growth through increased photosynthetic rates and through improved water-use efficiency (Steffen and Canadell 2005). However, the magnitude and extent to which effects are sustained under different conditions in different tree species are not clear. Booth et al. (2008) have summarized some of the conflicting observations that have been reported for Australia. Forest growth rates may well be increased in some cases by rising levels of atmospheric CO_2, but rising temperatures, higher evaporation rates and lower rainfall may lower growth rates in other cases. It is certain that there will be complex interactions. For example, benefits of increased water-use efficiency may not be realized in some cases because of poor soil nutrition.

Many subtropical forests, especially where water is limited, regularly experience daytime temperatures above 35 or even 40°C, and will do so more frequently in future. Temperature responses and adaptive potential at these extremes is an under-researched area. A possible consequence of increasing temperatures above the physiological optimum (which tends to be lower in C_3 than C_4 species) is declining primary productivity and decreasing soil and biomass carbon stocks. High temperatures and longer drought

Box 3.2 Impacts of climate change on biodiversity in South Africa

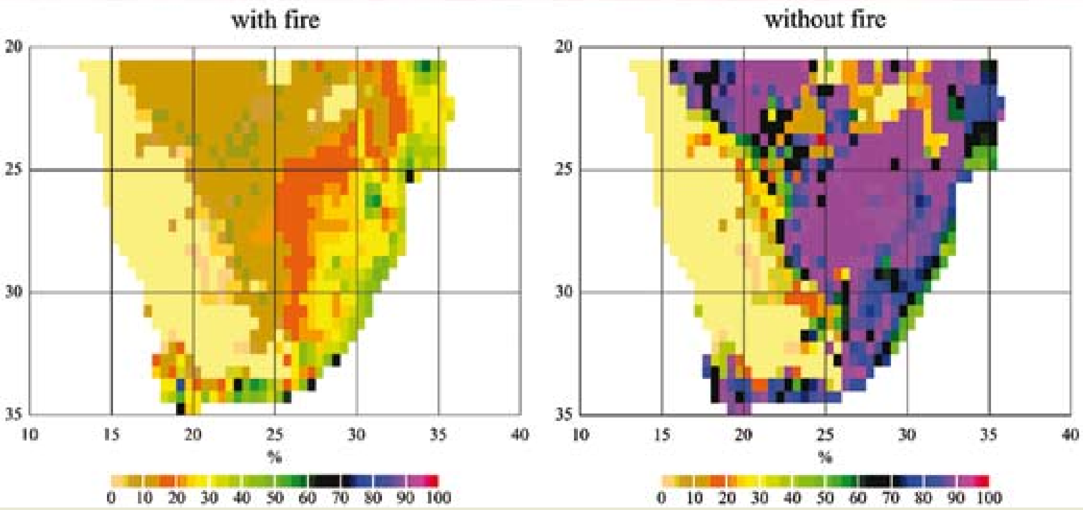

Figure 3.12 DGVM simulation of the current tree cover in southern Africa with (bottom left) and without (bottom right) the occurrence of fire (Bond et al. 2003b, copyright Elsevier. Reprinted with the permission of Elsevier. See also Bond et al. 2003a, Bond et al. 2005). The model indicates that the present preponderance of savanna woodlands and grasslands would probably be replaced by denser forests if fire frequency was much reduced or fire tolerance of trees and shrubs increases

Evidence of impacts of climate change on ecosystems is now emerging for southern Africa. For example, expansion of tree cover into the formerly open grasslands and savannas (bush encroachment) began around the 1960s, which may have been caused by the steadily rising global CO_2 concentration. In addition, the area considered climatically suitable for South Africa's seven existing terrestrial biomes could shrink by 35–55% by 2050 under scenarios from cluster *stable* (Midgley et al. 2001, p. 4). A disturbing prediction is the likelihood of the loss of the Succulent Karoo biome, home of the world's largest diversity of succulent flora and arguably the world's most botanically diverse arid region (Hannah et al. 2002). Countrywide, habitats are expected to shift along a west-to-east gradient of aridity, leading to an increased rate of extinction, as movement and available intact habitats are greatly restricted today. In southern Africa, fire-maintained systems have high species diversity compared to forest systems with fire suppression. The Cape Floral Kingdom (fynbos) is a biodiversity hotspot with over 7000 species, of which 68% occur nowhere else in the world (Gibbs 1987). The fynbos occurs in the winter rainfall regions and would be threatened by any change in rainfall that would alter the fire regime that is critical to the life cycle in the fynbos. With increasing atmospheric CO_2 levels, woody plants will reach fireproof levels more rapidly, as seen worldwide with tree density generally increasing in savanna woodlands (e.g. Bond and Midgley 2000). A great change in grassland biota will be expected if this level of bush encroachment into fire-dependent systems continues (e.g. Archer 1991). Simulations of current tree cover with and without fire occurrence show that savanna woodlands will be replaced by dense forests (Bond et al. 2003b, Bond et al. 2003a, Bond et al. 2005, Figure 3.12). Fire policy is contentious because human-induced fires are still frequent but not deliberately started by managers. The options are to manage for landscape heterogeneity, using patch mosaic burns, or use frequent intense burns over broader areas to maintain their current state.

increase vegetation flammability. According to the IPCC Fourth Assessment Report, drought stress has impacts on vegetation and has reduced gross primary production by as much as 30% in southern Europe, resulting in a net carbon source, particularly during the heat wave of 2003 (Fischlin et al. 2007, p. 217). In Portugal, the area burnt was almost twice that in the previous year and four times the 1980–2004 average.

Carbon: The structure, productivity and carbon balance of subtropical forests and savanna woodlands are sensitive to major climate-change drivers. CO_2 has contrasting direct effects on the dominant functional types – trees benefit from rising CO_2 but not from warming, while grasses benefit from warming but not from CO_2 increase – with uncertain, non-linear and rapid changes in ecosystem structures and carbon stock being likely (Fischlin et al. 2007). Carbon stocks are expected to be greatly reduced under more frequent disturbance, especially fire and droughts (e.g. Bond et al. 2005). In the savannas, reduced carbon sequestration is attributed to enhanced soil respiration through warming, fire regime changes and greater rainfall variability, but possible regional carbon gains through increased woody cover cannot be excluded.

Water: Climate change will bring drier, hotter and windier conditions to many regions, especially the areas with a mediterranean climate. These conditions will increase bushfire risks. Impacts of bushfires (as well as other factors such as drought) on species composition and re-growth, and consequent effects on catchment water yield, have been measured and modelled in Australia, but more for temperate than for subtropical forests. Factors such as bushfires affecting a site's capacity to store water in the canopy (via changes in canopy cover and leaf area index), litter layer (via changes in litter cover) and soil (via changes in soil water-holding capacity) will, in turn, affect water loss from interception, evaporation, transpiration and runoff.

Some rainfall runoff models using simple evaporation coefficients (e.g. Beare and Heaney 2002) have shown that climate change had the greatest effect in reducing annual stream flow in higher rainfall areas. To project reliably the influence on stream flow of various climate-change scenarios, modelling should account for the effect of changing climate on forest growth rates and how this will in turn affect evapotranspiration. For example, based on a projected 11% decrease in annual rainfall over 30 years, a change in water yield from a eucalypt-dominated catchment in south-western Australia of between 9 and 40%, depending on the changes in evaporation, resulted, but it was noted that confidence in the calculations of runoff could be significantly improved by using better estimates of the leaf-area index and potential evapotranspiration (Bari et al. 2005).

There is a statistically significant link between rainfall and stream flow and the El Niño-Southern Oscillation in eastern Australia (Australian Greenhouse Office 2003). In the drier regions of eastern Australian subtropical eucalypt-dominated woodland, the percentage change in runoff can be more than four times the percentage change in rainfall (Chiew and McMahon 2002). Most projections for decrease in runoff in the eastern Australian subtropical forest region are in the order of 7–35% by 2030 or 2050. In most parts of Australia, temperature increases alone have negligible impacts on runoff when compared with altered amounts of precipitation. However, most models used to project catchment water impacts of climate change, whether used in USA or Australia, do not take into account or adequately deal with vegetation impacts, such as the potential for reduced tree cover (Photo 3.2).

Dry land salinity is mainly a problem in the 400–800 mm rainfall zone, mostly in woodland-dominated 'crop-livestock' regions of Western Australia and the Murray-Darling Basin of eastern Australia (drier subtropics), and both land and stream are affected. A drier and hotter climate would result in reduced runoff and recharge to groundwater, with water tables being lower and hence salinity expression stabilized or reduced (Beare and Heaney 2002), a result already being experienced over the last decade in the northern wheat belt of Western Australia (George et al. 2008). This could be countered to some extent by an increased incidence of flooding. Native vegetation in these regions has been largely cleared for agriculture over the last century. The impact of planted forests (mainly eucalypts) on farm land to counter salinization would depend on growth and water-use efficiency as influenced by climate change.

Fire: Greater fire frequencies are already reported in the Mediterranean basin regions. Double CO_2 climate scenarios increase wildfire events by 40–50% in California and double fire risks in the Cape Fynbos, favouring re-sprouting plants, fire-tolerant shrub dominance in the Mediterranean basin, vegetation structural change in California and reducing net ecosystem productivity and, thus, carbon sequestration (Fischlin et al. 2007, p. 227).

Forests of subtropical areas are likely to be affected by changes in drought and fires. In both historical and future scenarios, fire is required for the co-existence of trees and grasses when deep soil water is available to trees. Simulations of tree/grass interactions under various climate-change scenarios indicate that more fires with higher temperatures resulted in decreased fuel moisture. Fire also increased in the deeply rooted grass scenarios because grass biomass, which serves as fine fuel source, was relatively high (Daly et al. 2000).

Pests and disease: For discussion of pests and disease in the subtropics and tropics, see this report, sub-chapter 3.7.4.

3.6.5 Future Opportunities and Services at Risk

Opportunities: Contrary to the pattern expected in boreal and temperate forests, both the frequency and intensity of fires in subtropical forests will eventually decrease after an initial phase of increase once rainfall has decreased so much that less grass fuel is available to support fires. Furthermore, the fraction of the landscape burnt tends to decrease with increasing human population density. A reduction in fire frequency and intensity, all else being equal, is expected to shift the tree/grass balance towards trees.

Ecological models do not suggest large near-term additional disturbances in native subtropical forests, and the largest impacts in the near future are likely to result from deforestation rather than from climate change (Gitay et al. 2001). However, many subtropical countries are increasing their share of the global timber market from plantations. Short-rotation exotic species, especially, are expected to be particularly suitable for adaptation during climate change, so that both tropical and subtropical countries could potentially benefit from climate change for increased timber production (Sohngen and Sedjo 2000). The effects in subtropical and tropical countries are directly linked to the size of higher primary productivity implied by climate change. It was projected that subtropical regions in Chile, Argentina, Brazil, South Africa, Australia and New Zealand could provide more than 30% of the market share in the middle of the century (Daigneault et al. 2008). If climate change drastically increases primary productivity in these plantations, large market impacts could result. Since most subtropical plantations focus on short-rotation species, of 10–20 years, timber managers can adjust and adapt rapidly if climate change has drastic effects. However, the sustainability of plantations is not beyond problems such as from pests or pathogens and on the long-run it may be preferable to manage plantations as part of an entire landscape within a framework of sustainable forest management (cf. e.g. Chapters 1, 6).

Vulnerabilities: Studies of the impacts of climate change on natural forest ecosystems projected contrasting scenarios, depending on precipitation patterns. In Mexico, simulations indicate that subtropical forests will increase in area because of projected increase in rainfall (Villers-Ruiz and Trejo–Vazquez 1998). In contrast, simulations for both Pakistan and Zimbabwe show a reduction in the area of natural forest ecosystems and an overall negative impact because of drier conditions (Matarira and Mwamuka 1996, Siddiqui et al. 1999). Drier conditions would also increase the risk of bushfires in many countries, especially in the Mediterranean basin.

The subtropical domain contains many key biodiversity hotspots in Latin America, southern Australia, the Fynbos or Succulent Karoo in South Africa, recognized as United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Sites. Many of these areas have been found in quantitative studies to be at particular risk from climate change (see also Box 3.2), since the majority of endemic species were projected to decline under a wide range of climate-change scenarios ranging from clusters *stable* to *growth* (e.g. Midgley et al. 2002, Thomas et al. 2004, Thuiller et al. 2006, Fischlin et al. 2007, Fitzpatrick et al. 2008).

John Innes

Photo 3.2 Sub-tropical *Taxodium distichum* swamp in the Everglades, Florida, USA. Forests dependent on specific water levels will be particularly sensitive to climate change.

3.6.6 Key Vulnerabilities

Within the subtropical domain climate change is likely to increase fire frequency and fire extent in the near future and beyond, although fires will later diminish due to lack of fuel grass. According to the risk analysis by Scholze et al. (2006), using 16 climate models under various scenarios of climatic change, one of the main ecosystem services at risk is loss of water supply, because of more frequent drought and high fire risks in subtropical Africa, Central America, southern Europe and eastern USA. Substantially larger areas will be affected and/or much more negative impacts will result from global warming beyond 3°C (*growth*) compared to a warming of only 2°C (*stable*) relative to preindustrial levels. Climate change has been projected to pose a very severe threat to biodiversity, in particular, since the subtropical domain contains some of the most prominent biodiversity hotspots in Latin America, Australia and South Africa, leading to probable cascading consequences for ecosystem functioning and the production of goods and services.

3.7 Tropical Domain

3.7.1 Types of Tropical Forests

Tropical forests are found between 25°N and 25°S and cover an area of about 17.5 Mkm^2 (Fischlin et al. 2007). They can be minimally grouped into evergreen moist or rainforests, tropical seasonal or drought-deciduous forests (moist savannas) and tropical dry forests (dry savannas). Rainforests are characterized by warm temperatures (annual mean >24°C) and high (≥2.5m/a) and regular precipitation throughout the year. They are found along the equatorial zone between 5°N and 5°S, are evergreen or semi-evergreen and include various geographical landscapes: lowland, mountain and swamp. Precipitation is at least twice the potential evapotranspiration. Tropical seasonal forests are characterized by a ratio of precipitation to potential evapotranspiration between 2 and 1, whereas tropical dry forests are characterized by a ratio <1. Seasonal forests are found in tropical monsoon regions or other seasonal tropical wet-dry climate zones and are moist deciduous, i.e. the trees shed their leaves in the dry season. All tropical forests, as defined here, typically require monthly temperature means to remain above 15.5°C (Prentice et al. 1992). Subtropical forests, typically characterized by dry conditions as found north or near 25°N and south or near 25°S, respectively, are discussed together with tropical dry forests in a separate sub-chapter (this report, sub-chapter 3.6).

3.7.2 Main Services Provided

Productivity: Tropical forests provide a wide range of provisioning services that include not only production of the highly valued tropical timber for domestic and international markets, but also many non-wood products and goods for the local population, including the livelihood of many indigenous peoples (e.g. Gitay et al. 2001, Hassan et al. 2005, Reid et al. 2005).

Regulation: Tropical forests provide major regulating services. Regionally and locally, forests control air humidity, soil moisture and water evaporation, and therefore the local and regional climate, by regulating the hydrology through photosynthesis and the canopy cover. Tropical forests regulate not only the microclimate, as provided by forests in general, but also the continent-wide climate by sustaining higher precipitation levels compared to regions without a forest canopy (e.g. Laurance and Williamson 2001, Semazzi and Song 2001, Betts et al. 2004, Bruijnzeel 2004, Negri et al. 2004, Werth and Avissar 2004, Avissar and Werth 2005, Field et al. 2007a).

Long-term monitoring of plots in mature humid tropical forests concentrated in South America revealed that forests gain biomass by tree growth exceeding losses from tree death by 0.71+/– 0.34 tC/ha (Phillips et al. 1998). Several authors have reported such gains in primary productivity of many tropical forests (e.g. Phillips et al. 2002a, Baker et al. 2004, Laurance et al. 2004, Lewis et al. 2004a, Lewis et al. 2004b, Phillips et al. 2008, Lewis et al. 2009), whereas others have found a deceleration of growth (Feeley et al. 2007) possibly due to changes in the water regime (Malhi and Wright 2004, Boisvenue and Running 2006, Feeley et al. 2007), while others have pointed at the increasing dominance of the tree growth suppressing parasitic lianas (e.g. Phillips et al. 2002b, Wright et al. 2004) or other causes possibly slowing down growth (e.g. Malhi and Phillips 2004, Betts et al. 2008).These findings suggest that undisturbed tropical old-growth forests are currently a significant carbon sink. For the Amazon alone this sink was estimated to be 0.6 PgC/a (Phillips et al. 2008), for Africa 0.34 PgC/a and for all tropical forests 1.3 PgC/a (Lewis et al. 2009).

Biodiversity: Tropical forests, in particular rainforests, are estimated to harbour the highest, biodiversity of all land ecosystems (e.g. Gentry 1992, Leigh et al. 2004) amounting to more than half of terrestrial and about a quarter of global biodiversity (Myers et al. 2000), supporting a vast range of services to people (e.g. Fearnside 1999). 15 out of the worldwide 25 biodiversity hotspots are found in the global tropical domain (e.g. Myers et al. 2000, Webb et al. 2005). The diversity in these forests is not exactly known and can only be estimated approximately (May 1990, Gentry 1992). Nevertheless, many studies provide strong evidence that climate change may lead to major biodiversity losses on all continents (e.g. Bazzaz 1998, Ravindranath and Sukumar 1998, Miles et al. 2004, Possingham and Wilson 2005, Stokstad 2005, Malhi et al. 2008), with consequent effects on other goods and services from these forests (Photo 3.3).

3.7.3 Current Opportunities and Vulnerabilities

Opportunities: Under elevated atmospheric CO_2 concentrations many species show a physiological response, e.g. by changing their photosynthetic rate. In general, increased CO_2 concentration stimulates plant growth and is beneficial to forests and crops in the humid and sub-humid tropics, particularly if nutrient limitations are absent or marginal (Baker et al. 2004, Lewis et al. 2004a, Lewis et al. 2004b, Zhao et al. 2005).

Vulnerabilities: Tropical forests are sensitive to global climate change and may be so severely impacted in structure and function that their services are greatly threatened (e.g. Betts et al. 2008). Bazzaz (1998) argued that tropical forests are sensitive to climate change for the following reasons: Firstly, a small change in climate could affect phenological events (such as flowering and fruiting) – some highly tuned to current climatic conditions, which may escalate to major impacts on the forest's biodiversity. This may even lead to changes in the role of the entire ecosystem in the global carbon cycle. For example, fruit-dependent animals are vulnerable to the consequences of changes in plant phenology (Corlett and Lafrankie 1998). Secondly, co-evolution produced interactions among specific plant and animal species, such as pollination and seed dispersal, with a high degree of specialization and strongly interdependent (Bazzaz 1998). Thirdly, many species in tropical forests have narrow niches because the diversity per unit area is very high (e.g. Erwin 1988, Gentry 1992, Leigh et al. 2004, Wills et al. 2006). Since opportunities for upslope displacement of endemic species with low adaptive capacity are limited in the tropical domain (e.g. Australia – Williams et al. 2003, Africa – McClean et al. 2005, Latin America – Raxworthy et al. 2008), climate change is considered to pose considerable risks for tropical biodiversity (e.g. Miles et al. 2004, Fischlin et al. 2007, sections 4.4.5, 4.4.11). Fourthly, deforestation

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Photo 3.3 Tropical forests, notably rainforests, harbour the majority of terrestrial biodiversity. Although research is less thorough than in other domains and quantitative estimates of diversity are difficult to obtain in the tropical domain, current knowledge robustly shows that tropical forests with their high endemism are of key relevance for the preservation of the Earth's biodiversity. Left: Primary rainforest stream scene within Gunung Mulu National Park, Sarawak, Borneo. Right – top: Flower of the worlds largest flowering plant from genus *Rafflesia*, at Poring Hot Springs, Borneo. Right – bottom: A Tomato Frog (*Dyscophus antongilii*) found at night in a tropical primary rainforest in the Makira Forest, Madagascar. Amphibian species such as the Golden Toad from Costa Rica's Monteverde cloud forests are among the first species possibly having gone extinct due to climate change (cf. review of extinction risks from climate change in Fischlin et al. 2007, section 4.4.11, p. 230, Figure 4.4, Table 4.1).

and other forms of anthropogenic disturbances may have significant ramifications, including impacts on tropical biodiversity (e.g. Pimm and Raven 2000, Pitman et al. 2002, Phillips et al. 2008), a situation in which climatic change is expected mainly to exacerbate the threats to biodiversity (e.g. Fischlin et al. 2007 [section 4.4.11], IPCC 2007b).

Non climatic drivers: Many humid and subhumid tropical forests are degraded by human activities such as pasture and commercial agriculture expansion, high-intensity logging, including shifting cultivation, fire, mining, and generally an overexploitation of forest resources, e.g. unsustainable logging (Zhao et al. 2005).

In particular, the continued conversion of large areas of humid tropical forests to pasture or other agricultural land uses (Houghton 2007) is understood to be a major driver for ecosystem change and loss of biodiversity in Amazonia (Watson et al. 1997). Substantially large deforestation in Amazonia can reduce evapotranspiration that would lead to less rainfall during dry periods in large forest and rangeland areas, with mountain ecosystems and transitional zones between vegetation types. The superimposition of global warming-driven climate change could make these areas extremely vulnerable to change (Watson et al. 1997).

In tropical Asia climate change will also add to other pressures resulting from rapid urbanization, industrialization and economic development (Hassan et al. 2005). These trends have often led to unsustainable exploitation of natural resources, increased pollution, land degradation and numerous other environmental problems (Watson et al. 1997).

In Africa, tropical forests and rangelands are currently under threat from population pressures and land-use systems (e.g. Achard et al. 2002, Hassan et al. 2005). Apparent effects from these pressures include rapid deterioration in vegetation cover, biodiversity loss, and depletion of water availability through destruction of catchments and aquifers (Watson et al. 1997). Floristic biodiversity hotspots, such as the mountains of Cameroon and the Afromountain habitats that stretch from Ethiopia to the higher latitudes of Africa at altitudes above 2000 m, could be threatened by shifts in rainfall patterns.

Biodiversity on the mountains could be at risk from an increase in temperature, and because migration may be impeded (Zhao et al. 2005).

3.7.4 Projected Future Impacts and Autonomous Adaptation

Projected future responses of tropical forests to environmental change show significant variation, partly due to incomplete data from that region, to differences among the models of ecosystem function derived from the existing databases, and to differences in future climate scenarios generated by the GCMs (Aber et al. 2001, Zhao et al. 2005). Since particularly tropical forests are subject to many other human made pressures, notably land-use change, impacts of climate change need to be discussed together with those other changes. However, such research is challenging and is particularly lacking in the tropics, which impedes assessments of the impacts of climate change for this domain.

Ecosystem shifts: In the long term, significant shifts in the spatial distribution and extent of tropical forests are very likely, not least because of the interaction of climate-change impacts with the many non-climatic environmental changes taking place in the tropics (e.g. Huntingford et al. 2008, Nepstad et al. 2008).

In Thailand, for example, the area of tropical forest has been projected to increase from 45% to 80% of total forest cover, whereas in Sri Lanka, a significant increase in dry forest and a decrease in wet forest could occur due to climate change (Watson et al. 1997).

Major changes are also projected for the tropical rainforest of north Queensland in Australia (Hilbert et al. 2001), in part because of its constrained geography. An increase in global temperature by only 1ºC causes the area of lowland mesophyll vine forest environments to increase, and results in a loss of core environment for endemic vertebrate species in lowland and mid-altitude areas. Depending on the precipitation, the upland complex notophyll vine forest environments respond positively or negatively. Increased precipitation favours the rainforest types, whereas decreased rainfall increases the area suitable for forests dominated by sclerophyllous genera such as *Eucalyptus* and *Allocasuarina*. The habitats for many endemic vertebrates on the highlands are projected to decrease by 50% threatening many endemic species with eventual extinction. Many endemics are especially vulnerable because the capacity to latitudinal dispersal is relatively limited (Williams et al. 2003). A complete loss of the core environment would occur if the temperature increased by ≥5°C (see also Fischlin et al. 2007). Substantial elevation shifts of ecosystems in the mountain and upland areas of tropical Asia are projected for most climate-change scenarios (Watson et al. 1997). Some authors have reported significant effects of climate change on soil erosion from experiments in central Nepal, leading to deposits on agricultural lands, in irrigation canals and streams affecting crop production (Sivakumar et al. 2005).

In the tropics the ability of species to reach new climatically suitable areas will be further constrained by habitat loss and fragmentation and by their ability to migrate to and survive in appropriate surrogate eco-zones – autonomous adaptation processes – which could also be affected by alien invasive species (Thomas et al. 2004, Fischlin et al. 2007, Ward and Masters 2007). Also due to such mechanisms tropical forests in Central America and Amazonia, are at significant risk from climate change (Scholze et al. 2006). A number of climate models projected under scenarios from cluster *stable* (2xCO_2) suggest a reduction of low-level cloud formation in regions such as in Monteverde and elsewhere in Costa Rica. Changes in the dynamic equilibrium of the cloud forests trigger altitudinal shifts in species ranges, subsequent community reshuffling, biodiversity losses and possibly even forest dieback (Foster 2001).

Water: Possible consequences for water balance in combination with higher temperatures and changes in precipitation under *stable* to *growth* scenarios (global warming 2–3°C over pre-industrial levels) showed an increase in runoff in most parts of tropical Africa and north-west South America, and less runoff in west Africa and Central America (Scholze et al. 2006). High risks of reduced runoff resulted from simulations with an increase in global mean temperature >3°C (*growth* or *fast growth*) in Amazonia, Central America and western Africa. The large variations in rainfall, which cause either drought or flooding in South and Central America, are associated with the ENSO (see glossary) phenomenon (Sivakumar et al. 2005). The properties of a large proportion of tropical forests vary with the seasonal availability of soil water. Species lacking morphological or physiological adaptation, such as some evergreen species, may not survive under water-stress conditions, which ultimately could alter species composition (Zhao et al. 2005).

Losses of tropical forest cover due to climate change according to scenario *growth* (e.g. Huntingford et al. 2008) are expected to feedback on hydrology, both regionally and globally (cf. this report, sub-chapter 3.7.2, e.g. Webb et al. 2006, Bala et al. 2007, Cowling et al. 2008, Nepstad et al. 2008).

The impacts of climate variability and change in the arid and semi-arid tropics of Africa can be described as those related to projected temperature increases, probably leading to increased open water and soil/plant evaporation in combination with precipitation decreases. Desertification in Africa is an example of declining mean rainfall during the last half of the 20th century that has caused a 25–30 km south-west shift in Sahel, Sudan and Guinea vegetation zones at an average rate of 500–600 m/a (Zhao et al. 2005). Similarly, soil moisture is likely to decline in Asia, and therefore the least dryland type (dry sub-humid drylands) is expected to become semi-arid and semi-arid land is expected to become arid (Sivakumar et al. 2005).

Fire: Fire risks have generally increased because warmer temperature together with decreased land precipitation or prolonged drought is likely to accumulate fuels from dying vegetation (Nepstad et al. 2004). With a likely increase of droughts due to a prolonged dry season or the ENSO driven phenomenon of inter-annual variability, the incidence of forest fires is also expected to increase (Alencar et al. 2006). In Asia, climate change may influence fires, which in turn could significantly affect the structure, composition and age diversity of forests in that region. In particular *growth* and *fast growth* scenarios project significantly more frequent forest fires in the arid and semi-arid regions of Asia. More frequent wildfires are also likely in South America, including Amazonia, which are particularly pronounced under *growth* scenarios (>3°C, Scholze et al. 2006). Moreover, drier conditions can trigger insect damage or cause large-scale vegetation shifts (Shlisky et al. 2007).

Pests and disease: Primary forests, secondary forests, plantation forests and agroforestry systems of the subtropics and tropics all experience strong effects from plant pests and pathogens (e.g. Goyer 1991, Su-See 1999, Rice and Greenberg 2000, Mitchell 2002, Wingfield and Robison 2004, Bell et al. 2006, Heath et al. 2006, Ofori and Cobbinah 2007, Hall 2008b). Under all clusters of climate-change scenarios, consequential changes in the strength and form of forest pestilence are anticipated, with greater changes in pestilence accompanying greater changes in climate.

Compared to more poleward ecosystems, where temperature changes are expected to be the dominant driver, patterns of pestilence in the tropics and subtropics are likely to be more responsive to changes in moisture availability. Regions that become dryer are likely to experience increases in tree mortality from various insect herbivores and pathogens as the tree species that are presently there become physiologically mismatched with the changing climate (Van Bael et al. 2004, Desprez-Loustau et al. 2006). Regions that become wetter are likely to experience increases in tree mortality from hydrophyllic pathogens (Jönsson 2006).

On the other hand, some areas may become suitable for valuable tree species because of reduced climatic suitability for some pests and diseases. Increased progress in the development of models that predict pest and disease systems across a range of climates could allow the more detailed predictions that are needed for the adaptive responses of humans interacting with these forests (Wharton and Kriticos 2004, Battisti et al. 2006, Avelino et al. 2007, Nahrung et al. 2008). In intensively managed forests (plantations and agroforestry), the near-term future of forest pestilence will also be influenced by the human-aided movement of pests and pathogens (Roux et al. 2006, Andjic et al. 2007), the choice of tree genotypes for planting (Stone 2001, Ramirez et al. 2004, Dhakal et al. 2005), the extent and patterning of low-diversity stands (Folgarait et al. 1995, Schroth et al. 2000, Staver et al. 2001), and changes in the surrounding landscape that influence the natural enemies of plant pests and pathogens (Terborgh et al. 2001, Cunningham et al. 2005, Tylianakis et al. 2007).

3.7.5 Future Opportunities and Services at Risk

Opportunities: Climate change in general will result in adverse impacts on the natural resources including forests even though some areas would benefit, such as increased rainfall in the highlands of east Africa and equatorial central America that would make marginal lands more productive than they are now (Watson et al. 1997). Even if greenhouse gas emissions were brought to a halt (*unavoidable*), further warming would still occur (IPCC 2007c, Figure 3.1). Even with such a modest rate of warming (0.6°C/century) and assuming otherwise minimal anthropogenic disturbances, some ecosystems are still expected to be affected by changes in their species compositions. However, mitigation of climate change could avoid or minimize many further adverse impacts projected to occur later. For example, the loss of tropical forests and grasslands could be avoided, although in the long run forest may switch from a carbon sink to a net carbon source, perhaps only as late as 2170 (Arnell et al. 2002). The areas with high biodiversity extinction risk are also reduced considerably with climate-change mitigation (Thomas et al. 2004, Fischlin et al. 2007, IPCC 2007b, IPCC 2007d).

Services at risk: Natural disturbance regimes such as fire, insects and disease may potentially affect forests, including their goods and services. This is now more widely recognized in the forest management portfolios of the majority of countries having tropical forests within their territory. However, these are not enough to stop changes in the remaining tropical forests. What is called for are effective climate mitigation to protect existing tropical forests from the negative impacts of climate change and a different form of development in tropical countries from that of now industrialized nations (Gullison et al. 2007). Finally, carefully regulated markets appear to be required to halt or at least to slow down widespread impoverishment and/or losses in the remaining tropical forests (Lewis et al. 2004a, Hall 2008a).

The climate in tropical Asia is characterized by distinct seasonal patterns associated with the two monsoon seasons and the occurrences of tropical cyclones in three cyclogenesis core areas (Bay of Bengal, north Pacific and South China Sea). The climate records show that the ENSO phenomenon has been more frequent and stronger since the 1970s (e.g. Trenberth and Hoar 1996, Trenberth et al. 2007) and has escalated the risk of drought and fire, adding to other pressures such as rapid urbanization, industrialization, unsustainable exploitation of natural resources, increased pollution, land degradation, and other environmental problems (Watson et al. 1997).

Seasonal and inter-annual climate variability contributes particularly to the vulnerability of many regions, e.g. in South America and Australia. Through disturbances such as drought and fire the ENSO phenomenon adversely impacts socio-economies, if those depend heavily on the production of the region's natural ecosystems. If coastal, such regions may also be particularly at risk from other extreme events such as future tropical cyclones. With warming tropical sea-surface temperatures, hurricanes are likely to become more intense, to have stronger peak winds, and to bring heavier precipitation (IPCC 2007d). Although some climate models project globally decreasing frequencies for tropical cyclones, significant uncertainties remain (IPCC 2007d).

3.7.6 Key Vulnerabilities

Carbon storage: Effects from elevated atmospheric CO_2 concentrations on sequestration of carbon in tropical forests are still debated (e.g. Morgan et al. 2001) and the evidence is not unequivocal (Fischlin et al. 2007, section 4.4.1). Phillips et al. (1998) showed that neotropical forests have acted as carbon sinks for the last three decades. Under the simplest scenario of a steady rise in forest productivity over time, it is expected that relatively slow-growing, but otherwise little changing, tropical forests would still act as carbon sinks, perhaps for a century and beyond. The actual magnitude and spatial distribution of this C-sequestration service are influenced by changes in the vegetation structure through changing climate and water availability (Cramer et al. 2001). However, the contribution of tropical forests in slowing down climate change by sequestering carbon has also been projected to diminish in coupled vegetation-atmosphere models, which explicitly consider feedback mechanisms (e.g. Cox et al. 2000, Cox et al. 2004, Cox et al. 2006, Friedlingstein et al. 2006). Simulations using a scenario from cluster *growth* (IPCC IS92a) show a terrestrial carbon sink during the 1990s of 1.4–3.8 PgC/a, but ~2090 the sink is reduced to 0.3–6.6 PgC/a (Cramer et al. 2004). Another land carbon-sink simulation found for the late 20th and throughout the 21st century a persisting sink with a strength of ~1 PgC/a (<2°C, scenario cluster *growth*). A global warming of 2–3°C, however, showed an increasing sink only up to the middle of the century and thereafter it declined (Scholze et al. 2006). Such sink saturation effects were found to occur possibly as early as in the first half of this century (Fischlin et al. 2007, Figure 4.2, p. 222). A global warming of >3°C showed that the sink increases, but less strongly up to the middle of the century, then declined and turned in some cases into a net carbon source towards the end of this century (Scholze et al. 2006). Assuming continuation of current trends of emissions and land-use change, IPCC reported recently that it is very likely that land ecosystems turn into a net source before the end of this century, thus, significantly accelerating climate change (Fischlin et al. 2007, p. 213, IPCC 2007b, p. 11).

Biodiversity: Climate change could be the biggest cause of increased extinction rates in many regions, especially in the tropics (Thomas et al. 2004, Fischlin et al. 2007), and land-use change, such as deforestation, is also an important and synergistic driver (cf. Sala et al. 2000, for a recent, comprehensive review see Fischlin et al. 2007). Deforestation and degradation through infrastructure development, plus non-sustainable practices, result in fragmented forests and biomass losses at large spatial scales, which could be greater in CO_2-induced climate change (Zhao et al. 2005). The results are again impoverished forests with reduced productivity.

3.8 Conclusions

At a worldwide scale, global change pressures (climate change, land-use practices and changes in atmospheric chemistry) are increasingly affecting the supply of goods and services from forests (Easterling and Apps 2005). Moderate climate change alone (*unavoidable*, *stable*) would already put some sensitive ecosystems within the tropical domain at a considerable risk, especially those transitional between two different vegetation classes or eco-zones. Climate change threatens biodiversity, including some of the most valuable biodiversity hotspots of Earth, risking not only major changes in species compositions, but also highly significant and irreversible biodiversity losses that will result in the loss of ecosystem goods and services with severe consequences for forest communities. Considering also anthropogenic disturbances such as forest fragmentation and poor capacity for fire management, many forest species are expected to have difficulty in moving to climatically suitable areas to survive (i.e. to adapt to climate change). Under scenarios of *growth* ('business-as-usual') or *fast growth*, the resulting rapid global change will continue to impact forests, with important consequences for the ecosystem structure, its biodiversity and its many provisioning, regulating and socio-economic services; these include hydrological regulation, carbon sequestration, fires, pests, pathogens and forest health in general as well as ecotourism and the subsistence livelihoods of indigenous peoples.

Forests harbour a large fraction of the Earth biodiversity, perhaps as much as three quarters of the terrestrial biodiversity, with the tropical domain containing very likely already one quarter. Many studies show significant biodiversity losses at the ecosystem, species and genetic levels. Species extinction rates are driven by the magnitude or intensity of climate change, since they affect species distribution and composition (Thomas et al. 2004, Fischlin et al. 2007). One study estimated global extinction risks, ranging from average extinction rates of ~18% (*unavoidable*, lower end *stable*), over ~24% (*stable*), to ~35% (growth Thomas et al. 2004). The comprehensive meta-analysis by IPCC (Fischlin et al. 2007) estimated that, on average, roughly 20–30% of vascular plants and higher animals are at an increasing risk of extinction as temperatures increase by 2–3°C above pre-industrial levels (IPCC 2007b, p. 11). Although current knowledge does not permit predictions of precise tipping points, where some degree of biodiversity loss leads to substantial changes in structure and functioning of ecosystems, it is very likely that the projected losses in biodiversity are highly significant and will result in consequential changes in the ecosystem services currently provided.

Based on the presented CCIAV assessment at the global scale as well as for each of the four domains – boreal, temperate, subtropical and tropical – the following key vulnerabilities were identified:

- Globally, forest ecosystems are sufficiently resilient and can adapt to impacts of limited climate change according to scenarios from cluster *stable*, particularly in currently temperature limited or humid climates, by maintaining similar or increased levels of productivity. However, in drier medium wet, semi-arid to arid climates, forest productivity is projected to decline. Regardless of changes in productivity, species compositions are projected to be significantly altered, e.g. from boreal to mixed-deciduous, from boreal to grassland, from mixed-deciduous to deciduous, or deciduous to savanna.
- Globally, forest ecosystems have difficulty adapting to impacts from climate change according to scenarios from cluster *growth* or *fast growth*, in particular in submesic, semi-arid to arid climates, where productivity may decline to an extent that no longer supports forests or even trees. In such cases forest systems will become grasslands, savannas, or even deserts. In humid climates, forests are projected to continue to grow or expand. The overall balance is positive for scenarios at the lower bounds, but tends towards a negative balance for scenarios at the upper bounds of cluster *growth*. Several models project a significant risk (>40%) of losing entirely current carbon-regulating services, as land ecosystems turn globally into a net source of carbon beyond a global warming of 3°C or more relative to pre-industrial levels. Such effects are projected to be even more pronounced in the next century, as development pathways from the upper end of clusters *growth* and *fast growth* are still far from having reached a new climate equilibrium by ~2100.
- Boreal forests are projected to increase their productivity, in the northern taiga even under scenarios from cluster *growth*. However, at the same time those forests are projected to be impacted by an increased prevalence of fires and insect pests, and the overall balance of losses in the southern areas vs. the smaller gains in the northern parts is likely to be negative, particularly within this century. Moreover, the carbon emissions from thawing and burning peatlands in northern boreal taiga systems are projected to further enhance climate change.
- Temperate forests are projected to increase their productivity in northern poleward areas for climate-change scenarios from cluster *stable*, whereas the equatorial areas show declining productivity under the same scenarios. The overall balance is more likely than not positive. However, for scenarios from cluster *growth* and *fast growth*, the overall balance is highly uncertain with considerable simultaneous risks from drought, fire, pollution, habitat fragmentation and possibly more opportunities for invasive alien species arising towards the end of this century and beyond. They are projected to tip the balance further towards the dominance of negative effects.
- Productivity in most subtropical forests is projected to decrease under a wide range of climate-change scenarios. Fire frequencies are expected to increase, yet may reach saturation or may even diminish when conditions become so dry that decreased production leads to less fuel accumulation. In this domain, several biodiversity hotspots are threatened by a wide range of climate-change scenarios, and the well-being of many people depending on current productivity levels is increasingly at risk.

- Tropical forests are projected to increase their productivity wherever sufficient water is available. However, in seasonal dry or otherwise drier climates, tropical forests are projected to decline. Not only significant provisioning but also globally important regulating services are at risk. Climate feedbacks from local climate to the global carbon cycle may have major implications for the global climate and may contribute towards an acceleration of climate change. Moreover, the tropical domain harbours major amounts of the Earth's biodiversity, and substantial biodiversity losses are to be expected.
- High altitude systems that maintain forests are expected to lose biodiversity as the capacity for these species to move to suitable climate domains is extremely limited. According to current understanding, tropical mountain forest species systems are most at risk in this regard.

Since our analysis showed that many forests are highly vulnerable to unmitigated climate change (scenarios from cluster *growth*), merely strengthening adaptation will be insufficient to maintain, let alone enhance, the multitude of ecosystem services forests currently provide. Moreover, since forests may release large quantities of carbon if impacted by climate-change stressors or otherwise degraded, they may exacerbate climate change unless such feedbacks are slowed down. Thus, what is called for in addition to adaptation is climate mitigation and lessening non-climatic pressures, notably a large reduction in fossil-fuel emissions as well as stopping deforestation, that effectively curb climate change and enable forests to maintain their adaptive capacity.

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4 Future Socio-Economic Impacts and Vulnerabilities

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Abstract: The projected impacts of climate change are significant, and despite the uncertainties associated with current climate and ecosystem model projections, the associated changes in the provision of forest ecosystem services are expected to be substantial in many parts of the world. These impacts will present significant social and economic challenges for affected communities and society as a whole, particularly among the forest-dependent poor, who are already highly vulnerable in many countries throughout the world. This chapter discusses how the likely effects of climate-induced changes on the provision of forest ecosystem services may affect the economic and social well-being of society, including forest-dependent people, with specific reference to the production of wood and non-wood products, hydrological regulation and water quality, human health and well-being, spiritual and cultural values, recreation and ecotourism. The role of governance is discussed as a key factor that will profoundly influence social and economic impacts and vulnerabilities, and the adaptive capacity of societies to deal with the effects of expected climate change-induced shifts in the quantity and quality of forest ecosystem services.

Keywords: climate change, socio-economic impacts and vulnerabilities, non-wood forest products, social resilience, forest-dependent, cultural services, traditional coping strategies, adaptive capacity and governance

■

4.1 Introduction

The expected impacts of climate change on forests and woodlands and their capacity to provide vital ecosystem services, as discussed in previous chapters of this report, will have far-reaching consequences for the well-being of people in affected areas. Modelling and analysis to date, as described in this chapter, has provided numerous insights for policy makers. As with any scientific endeavour, though, evaluations of the future socio-economic impacts and vulnerabilities of climate change are fraught with difficulties and uncertainties. As is widely recognized throughout the socio-economic literature, future projections of economic conditions are inherently uncertain. These uncertainties are compounded by the links economists make with the climate and ecological models that contain their own uncertainties, particularly when addressing impacts at subregional and local levels. These difficulties are compounded not only by the complexity of forest ecosystems and their responses to climate change, but also by the indirect nature of the links between provision of forest ecosystem services and human well-being.

Current projections of climate and ecological models indicate that forest productivity will increase over time in some regions (IPCC 2007, Fischlin et al. 2007), presenting new opportunities for forest industry and forest-dependent communities to capture economic benefits associated with these changes. In many other regions these same projections suggest significant declines in the capacity of forest ecosystems to provide production, provisioning, regulating and cultural services upon which a significant proportion of the world's population depends for their livelihoods.

Of particular concern are the potential impacts on forest-dependent communities in tropical and sub-

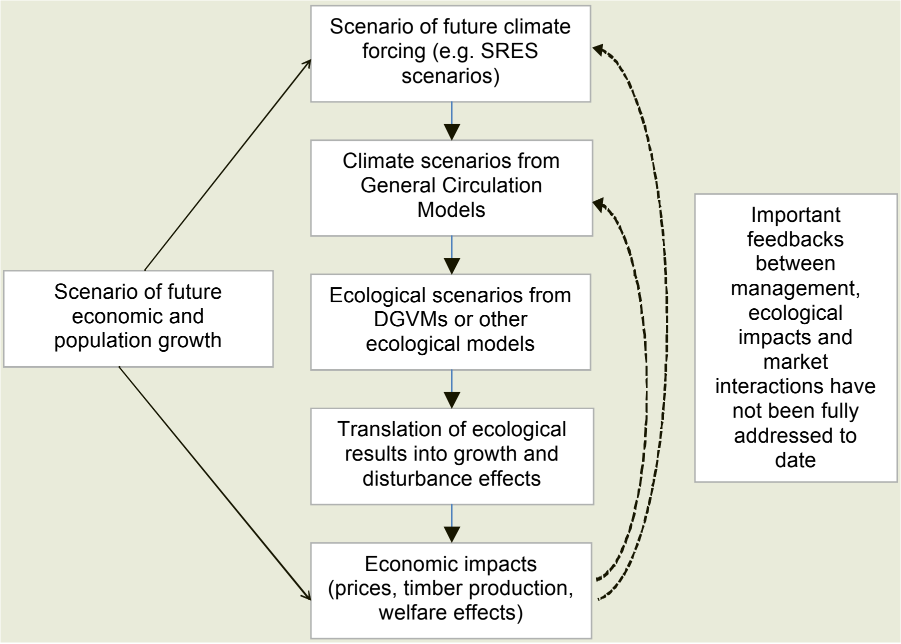

Figure 4.1 Stylized view of methods for assessing economic impacts of climate change.

tropical domains who are already suffering from the effects of ongoing deforestation and forest degradation. Projected increases in the frequency and severity of droughts, floods, other extreme weather events, forest disturbances such as forest fires and outbreaks of forest pests and diseases, and associated changes in forest structure and composition will further reduce the capacity of forests and woodlands to provide timber, fuelwood and essential non-wood forest products, sufficient clean water for consumptive use, and other services required to meet basic nutritional, health and cultural needs of forest-dependent people. In such regions, existing socio-economic vulnerabilities of these communities may be expected to worsen. As has been witnessed in the past, the inability of people to meet their basic requirements for food, clean water and other necessities which forest ecosystem services often provide can lead to deepening poverty, deteriorating public health, social conflict (as people seek to migrate to more hospitable areas, or already overcrowded urban centres) and other detrimental human impacts.

In this chapter, we consider how climate-induced changes on the provision of forest ecosystem services will impact the economic and social well-being of forest-dependent people. We consider these socio-economic impacts and vulnerabilities with reference to provisioning services (including production of wood and non-wood products, in sub-chapter 4.2); regulating services (hydrological regulation and water quality, human health and well-being, in sub-chapter 4.3); and cultural services (spiritual and cultural values, recreation and ecotourism, in sub-chapter 4.4). Supporting services are addressed in chapter 3. The role of governance is discussed in this chapter as a key factor that will profoundly influence social and economic impacts and vulnerabilities, and affect, positively or negatively, the adaptive capacity of societies to deal with the effects of expected shifts in the quantity and quality of forest ecosystem services as influenced by climate change.

Within social science research, many methods have been used to assess potential impacts of climate change in social systems. These methods either implicitly or explicitly account for adaptation.
For a description of these methods see Box 4.1.

4.2 Provisioning Services

4.2.1 Wood and Wood Products

Models and Methods to Assess Impacts of Climate Change on Wood Product Markets

Any assessment of climate-change impacts in wood-product markets requires inputs from other disciplines. For timber-market impacts, these inputs include scenarios of future climate change from general circulation models, and scenarios of ecological impacts from ecological models (e.g. dynamic global vegetation models, or DGVMs), as discussed in chapter 3. The results from ecological models provide an indication about the implications of climate

Box 4.1 Assessing Potential Climate Change Impacts in Social Science

Climate change is only one factor that will affect forests and people dependent on forest goods and services in the future. Population and income growth, expansion or reduction of crop and pastureland, pest infestations, forest fires and industrial pollution (e.g. nitrogen deposition or acid rain) are other factors that will affect the structure and function of forests in the coming century. To assess the impact of climate change on forest goods and services, the methods used must disentangle the effects of climate change from these many other important influences. Further, as noted by Rosenzweig et al. (2008), humans will adapt, and it is difficult to separate adaptation from the impacts. Within social science research, many methods have been used to assess potential impacts of climate change in social systems. These methods either implicitly or explicitly account for adaptation.

First, researchers may use evidence from adaptation of human systems to other types of impacts, or to historic climate change, to make inferences about how climate change may affect these same, or other, human systems (see e.g. 'vulnerability assessment' proposed by Turner et al. 2003). With such analysis, researchers assess how other observable factors (such as population change, agricultural expansion, disturbances, etc.), influence forests and the flows of goods and services provided by forests. This information is then used to make inferences about how climate change may affect these same flows of goods and services provided by forests, and the individuals or groups of individuals who use them. Analysis like this can help researchers better understand the resilience of families, groups of people, political systems or other entities to the small- or large-scale disruptions possible with climate change. In regions where climate change is already occurring and having impacts, such as in high altitudes and high latitudes, researchers are already using these methods (e.g. Young and Lipton 2006, Ford et al. 2008).

Second, researchers may employ empirical, or statistical, data that compares responses of economic or social systems across climate variables (see e.g. Mendelsohn et al. 1994, Schlenker et al. 2006, Deschenes and Greenstone 2007). To make such analysis valid, one must have a large number of observations over a fairly wide spatial scale. Researchers may also supplement this cross-sectional data with data from different time periods to strengthen the results. If a large number of studies are available assessing impacts on a particular resource (e.g. forests, crops, land use), one may also conduct meta-analysis. Meta-analysis involves combining the results of many different studies, perhaps from different regions, to assess whether the results can be generalized.

Third, researchers can conduct survey or experimental research designed to elicit hypothetical individual (or community) responses to climate-change stimuli (see e.g. Layton and Brown 2003). Studies conducted with survey methods or with experimental techniques can isolate responses to climate-change stimuli from other types of stimuli. However, it is important to recognize that in the absence of actual observed climate change, this data will be hypothetical.

Fourth, researchers can construct models to assess impacts on specific variables. Researchers often rely on models sufficiently empirical or statistical data is not available. Much of the research on the impacts of climate change on timber-market outputs has been conducted with modelling studies (see e.g. Joyce et al. 1995, Sohngen and Mendelsohn 1998, Sohngen et al. 2001, and Perez-Garcia et al. 2002). The models simulate market activity 'without' and 'with' climate-change stimuli. The two cases are compared to determine impacts on economic outcomes (e.g. prices, outputs). Because other factors in the model are constant in the 'with' and 'without' cases (population, income, etc.), modelling exercises isolate the impacts of climate change relative to other influences.

change on different ecosystem types, but these results must often be translated into data that can be used in economic models.

A stylized view of the steps typically taken to conduct an economic assessment of climate-change impacts is shown in Figure 4.1. Most assessments to date have assumed a linear path of models, that is, from climate scenario to ecological scenario to economic model. Some links between vegetation models and General Circulation Models have been established, but important feedbacks between management, ecological impacts and market interactions have not been fully addressed to date. This point is important to recognize because most ecological models assume that there is little, or no, interaction between humans and ecosystems. In reality though, many of the world's ecosystems are affected by human management, and most forests utilized for timber production are in fact managed. Ecological models that do not account for land management by

Table 4.1 Other factors, besides climate change, that would affect the demand or supply of wood.

Factor	Demand side effects	Supply side effects
Energy demand	Affect demand for wood as an input into energy production	Affect supply of land for forests
Agricultural markets	–	Affect competition for land and affect supply of forestland
Governance	Affect income and population growth and thus demand	Affect land tenure
Economic growth	Affect demand for wood	Affect demand for land in other uses, such as environmental protection
Exchange rates	Alter the quantity demanded	Alter production costs across countries

humans likely overestimate the impacts of climate change on ecosystems because they do not capture human responses either directly to climate change phenomena, or to secondary market adjustments caused by climate change (Sohngen et al. 1998).

Quite a lot of other factors, besides climate change, also will affect forests and forest management in the future (e.g. Table 4.1). Economic models of course could be used to study the effects other exogenous impacts have on timber markets, but would constitute a different study than one on climate-change impacts. All the economic models make assumptions about how the other factors described in Table 4.1 affect markets when they analyse climate-change impacts. Analysts typically hold their assumptions about these other factors constant between the baseline scenario and their climate-change scenario. Some studies do conduct sensitivity analysis to consider the implications of changes in one or another of the 'other' factors.

Ecological Impacts Captured By Economic Models

As discussed in Chapter 3 of this report, climate change could have many influences on forest structure and function, including changes in productivity, changes in disturbance, and the movement of species and ecosystem types across the landscape. Economists account for these effects by using results from the ecological studies to perturb their underlying inventory models. Within the economic literature, three ecological impacts have been studied to date: yield effects, disturbance regimes and movement of species and ecosystem types.

Yield Effects: The inventory models used by economists typically contain yield functions, which provide information on the quantity of biomass per hectare at different age-class intervals. These models do not incorporate the influence of climate on the yield projections. Ecological models typically provide information on changes in productivity of different ecosystem types and in some cases age classes, under different transient climate scenarios, and these changes can be used to perturb the annual growth of forests within the inventory models (Joyce 2007).

One important uncertainty in modelling growth effects in forestry is the influence of increasing atmospheric concentration of carbon dioxide (CO_2). Most ecological models used by economists to date have incorporated this influence on plant growth. A recent study by Haynes et al. (2007) illustrates the importance of (CO_2) effects. Their study shows that under climate change and elevated CO_2, softwood and hardwood inventories expand steadily (relative to the base run of no climate change or elevated CO_2 influence), while under climate change only, some forest types increase in timber growth, while growth in other forest types declines. This area of research on CO_2 effects on plants is a rapidly changing area of science, and economic model development can lag behind the current understanding of the science.

Disturbance Regimes: Changes in disturbance regimes such as changes in forest fire outbreaks, severe storm and wind damage, disease outbreaks, or insect infestations that lead to large areas of dead, dying and decaying trees – can have more immediate effects on markets than changes in forest yields. If forest dieback and disturbance occurs in managed forest zones, losses of existing stocks of trees could have immediate impacts in markets. The full range of economic impacts will depend on how extensive the damage to trees is and how much salvage can be conducted.

Movement of Species and Ecosystem Types: Ecological models indicate that ecosystem types will shift pole-ward and up-slope. Accounting for movement of species is the most difficult aspect of economic modelling due to the long time lags between regeneration and harvest of trees. The movement of tree species by humans is inherently a trial and error process. Natural migration rates within ecological models account for the natural trial and error process. Through active management, humans can speed this up, although investments will depend on prices. Humans may also make errors that will slow migration. There are many genetic studies showing the adaptability of commodity species across large geographical areas, but there is currently little research on the adaptability of non-commodity forest tree species.

Economic Estimates of Impacts in Timber Markets

There is a long history of modelling timber markets, both within countries and internationally. These models have been developed to assess the relationship between changing demand for wood products and the supply of timber. One example is the TAMM model (Adams and Haynes 1980), which was used widely throughout the 1980s and 1990s for timber supply analysis in the United States. More recently in the USA, the FASOM model (Adams et al. 1996) has been developed and employed for forest policy analysis in the USA. Whereas TAMM and FASOM models only consider the United States, The Center for International Trade in Forest Products Global Trade Model (CGTM; described in Kallio et al. 1987) and the Timber Supply Model (Sedjo and Lyon 1990) account for global demand and supply conditions. EFISCEN is a forest-sector projection model similar to TAMM and CGTM which has been applied widely to the European forest sector (Nabuurs et al. 2001). In the past 10–15 years, all of these models have been applied to assess climate change.

The recent IPCC report indicates that by the end of this century global warming could cause large-scale changes in the structure and function of ecosystems globally (Fischlin et al. 2007). While the most dramatic changes appear to occur later in the century, significant adjustments in forest stocks could occur within the next 20–50 years (Fischlin et al. 2007). Taking the ecological results into account, economic studies have thus far concluded that the global supply of timber is not likely to be adversely affected by climate change, and in fact could be increased (Easterling et al. 2007). The results in this chapter support this general conclusion from the IPCC, but the results here recognize as well that there are potentially large regional and local effects from climate change that will have important implications for citizens living and working within those affected forested areas.

Given the results in Easterling et al. (2007) and other economic assessments of climate change, consumers worldwide are expected to benefit from climate change due to expanding global timber supply and falling prices. Producers and landowners, on the other hand, could gain or lose welfare during climate change depending on relative productivity versus price effects. The results in this sub-chapter focus on impacts of climate change on output and timber producers.

Global Results

As a result of projected increases in the productivity of forested ecosystems due to climate change, a number of studies have projected that climate change will increase the long-run supply of timber globally (Perez-Garcia et al. 1997, Sohngen et al. 2001, Perez-Garcia et al. 2002, Lee and Lyon 2004). With the exception of Perez-Garcia et al. (2002), the other studies utilized earlier, static General Circulation Models. As a consequence, those authors had to make assumptions about the timing of the effects of climate change, assuming that the effects occurred linearly over a 50–100 year period.

Authors of existing studies also have focused on different types of ecological effects in their analyses. Perez-Garcia et al. (1997, 2002) used changes in either net primary productivity or total ecosystem carbon to adjust the annual growth of timber in different regions of the world. Because the ecological results suggested either more net primary productivity or ecosystem carbon in the long run in most ecosystems, the supply of timber expanded and timber market welfare increased.

Sohngen et al. (2001) used changes in net primary productivity to adjust annual growth as well, but they also accounted for disturbance and movement in species over time. To capture disturbance, they assumed that any change in ecosystem type from the baseline to the climate scenario resulted in dieback of the existing species. They then allowed the timber model to choose whether to regenerate new forest types in regions where dieback occurred if the new ecosystem type was indeed forest. In their model, the long-run supply of timber expanded because the overall area of forest land was projected to increase and net primary productivity in forests increased. Although they linearized the pace of the impacts, their results suggested that some regions, such as North America, could experience negative market outcomes, even though long-run productivity in forests was projected to increase.

Gerardo Mery: Roundwood exports from Chile

Photo 4.1 It has been projected that globally climate change will increase the supply of timber in the long term.

Regional Impacts

Regional impacts on outputs and producer returns from various studies are summarized in Table 4.2. The United States remains the most widely studied country in terms of estimates of economic impacts of climate change in timber markets (see Joyce et al. 1995, Sohngen and Mendelsohn 1998, 1999, Irland et al. 2001, Joyce et al. 2001, Alig et al. 2002). There are few studies of the economic impact of climate change on timber markets in other regions, although the global models do provide insights into the potential effects in most regions. Regional studies in these other regions are largely a collection of ecological assessments of the impacts of climate change on net annual increment, holding timber harvests at baseline levels (e.g. Lelyakin et al. 1997, Nabuurs et al. 2002).

By and large, studies in the USA have found that climate change likely will reduce prices for wood products and increase output in the USA. These changes will in turn benefit consumers, but potentially harm producers. Effects in the USA, however, have been found to vary from region to region. Sohngen and Mendelsohn (1998, 1999) suggest that producers in the southern and Pacific north-western USA could experience the negative economic impacts of climate change, while producers in the north-eastern and north central USA gain. Because climate change reduces prices, regions with large inventories of merchantable trees have the biggest potential losses in asset value. Burket et al. (2000) found similar results for the southern USA using a regional economic model for just that region. Alig et al. (2002), however, suggest that output is likely to expand more in the southern USA than the northern US as climate changes.

Results for the USA and Canada derived from global models are largely consistent with the regional analyses. Sohngen and Sedjo (2005) illustrate that output in North America depends on whether there are large-scale disturbance events related to climate change. Specifically, if climate change increases disturbance-related forest dieback, output in North America is projected to decline. The largest impacts on output are projected to occur in northern and western mountain regions, suggesting relatively larger potential impacts in Canada. Because prices are lower due to the expansion in global output, producer returns decline if dieback occurs in North America. The results in Sohngen and Sedjo (2005) illustrate how sensitive output and producer returns in regions of the world are both to changes in disturbance regimes and climate impacts in other countries. Although they do not explicitly account for changes in disturbance regimes, Perez-Garcia et al. (2002) also find that producer returns decline in Canada and the USA.

Table 4.2 Economic estimates of climate change impacts on output and producer returns.

Region	Output		Producer returns
	2000–2050	2050–2100	
North America[1]	–4 to +10%	+12 to +16%	Decreases
Europe[2]	–4 to +5%	+2 to +13%	Decreases
Russia[3]	+2 to +6%	+7 to +18%	Decreases
South America[4]	+10 to +20%	+20 to +50%	Increases
Australia/New Zealand[4]	–3 to +12%	–10 to +30%	Decreases & Increases
Africa[5]	+5 to +14%	+17 to +31%	Increases
China[5]	+10 to +11%	+26 to +29%	Increases
South-east Asia[5]	+4 to +10%	+14 to +30%	Increases

[1] Alig et al. (2002), Irland et al. (2001), Joyce et al. (1995, 2001), Perez-Garcia et al. (1997, 2002), Sohngen et al. (2001), Sohngen and Mendelsohn (1998, 1999), Sohngen and Sedjo (2005)

[2] Karjalainen et al. (2003), Nabuurs et al. (2002), Perez-Garcia et al. (2002), Sohngen et al. (2001)

[3] Lelyakin et al. (1997), Sohngen et al. (2001)

[3] Lelyakin et al. (1997), Sohngen et al. (2001)

[4] Perez Garcia et al. (1997, 2002), Sohngen et al. (2001)

[5] Sohngen et al. (2001)

Nabuurs et al. (2002) and Karjalainen et al. (2003) utilize the EFISCEN model to assess the influence of climate change on forest stocks and markets in Europe until 2050. Their results indicate that climate change will increase net annual increment in forests up to the middle of the century. They do not estimate the effects of these changes on consumers and producers, but they instead assume that harvests follow the same path with and without climate-change impacts on forest growth (suggesting that there would not any economic impacts in markets). Given the strong increase in net annual increment with climate change projected by their model, however, economic theory tells us that timber production would increase in Europe, and timber prices would fall as a result of climate change.

Sohngen et al. (2001) find that output in Europe increases with climate change this century. The results in Perez-Garcia et al. (2002) show both increases and decreases in output depending on the specific scenario in their analysis. Lower global timber prices in both models cause producer returns to decline as a result of climate change.

Lelyakin et al. (1997) examine the effects of climate change on Russian forests over a relatively short time period (until 2020). They show increased net annual growth through all of Russia by 2020, with the largest increases in the northernmost areas, suggesting that forest output in Russia would expand as climate changes. Sohngen et al. (2001) do show output expanding in Russia modestly up to 2050 (2–6% relative to base), but then more rapidly to the end of the century (7–18% relative to base). Producer returns in Russia decline despite the increase in output due to the reduction in prices caused by climate change.

Over the past 30 years, timber production in regions such as Australia, New Zealand and South America has increased dramatically, due to the expansion of fast-growing plantation species. For the most part, these trends are expected to continue, and strengthen, in the absence of climate change. For example, Perez-Garcia et al. (2002) suggest that output will expand 10–13% over the next 50 years in Chile, and Sohngen et al. (2001) suggest similar gains (10–20%) in output over the next 50 years in South America, with stronger gains thereafter (20–50%). The results in Sohngen et al. (2001) do show potential losses in output in Australia and New Zealand as a result of the ecological predictions they used.

Only one of the studies with results reported in Table 4.2 has examined impacts in developing regions, such as Africa, South-east Asia and China. The results of that study (Sohngen et al. 2001) indicate that output and forestry revenues increase in the countries of those regions due to rising timber yields and adaptation by shifting to shorter rotation species. As in South America, foresters are projected to expand their output by continuing a shift towards short rotation species as climate changes.

Table 4.3 Global import values of selected NWFPs for 1992–2002 (FAO 2005a).

Commodity description	Global import value (1000 USD) 1992	2002
Mosses and lichens for bouquet, ornamental purposes	9 352	25 476
Truffles, fresh or chilled	4 201	23 656
Mushrooms other than agaricus, fresh or chilled	n.a	364 412
Mushrooms & truffles, dried	n.a	219 548
Plants & parts, pharmacy, perfume, insecticide use	689 926	777 980
Rattan used primarily for plaiting	118 987	51 327
Maple sugar and maple syrup	43 632	116 202
Ginseng roots	38 345	221 435
Palm hearts, otherwise prepared or preserved	16 082	67 514
Oak or chestnut extract	8 653	917
Gum Arabic	101 312	105 510
Natural cork, raw or simply prepared	7 874	110 702

4.2.2 Non-Wood Products

Importance of Non-Wood Forest Products to Forest-Dependent Communities

Forests and woodlands are increasingly recognized for their precious biological resources beyond timber which sustain the livelihoods of hundreds of millions of people in forest-dependent and adjacent agricultural communities, and contribute significantly to their domestic energy, food- and health-security needs. These non-timber forest resources include fuelwood and charcoal, and wood used for tools, carving and other household purposes; they also include non-wood forest products (NWFPs) such as livestock fodder, gums, resins, honey, fruits, nuts, tubers, mushrooms, spices, fish, wild meat and other wild foods, plants and oils for pharmaceuticals and cosmetic products, as well as rattans and bamboos (De Beer and McDermott 1989, FAO 1995, 1999, CIFOR 1999, Belcher 2003). For the rural poor living in and adjacent to forests, NWFPs provide essential food and nutrition, medicine, fodder, fuel, thatch and construction materials, mulch and non-farm income. Forests often serve an important 'safety net' function, providing some measure of relief during the 'hunger periods' in the agricultural cycle through their provision of wild foods (Arnold and Townson 1998, Falconer 1990, McSweeney 2004).

Despite their importance to forest-dependent people worldwide, accurate information on marketing and use of NWFPs is limited and often mixed with agricultural production statistics. The 2000 FAO Forest Resources Assessment (FRA) NWFP component found a significant lack of quantitative data at the national level on both NWFP resources and products (FAO 2001). Statistical data, if accessible at all, is limited to export data for a selected number of internationally traded NWFPs. For the industrialized temperate and boreal countries, data on quantities and monetary values (global import values) are available for Christmas trees, cork and a number of species of mushroom (such as truffles), berries, medicinal plants, decorative foliage, game meat, hides and pelts, honey and nuts (see Table 4.3).

Through their experience with forest-dependent communities, forestry experts have recently begun to appreciate the enormous significance of NWFPs for sustaining rural livelihoods. In recent years, a growing body of scientific research has shown that, given certain basic conditions, non-wood forest resources can help communities to meet their needs on a sustainable basis (FAO 1995). There is strong evidence that the poorest of the rural poor are the most dependent on forests and woodlands to meet their domestic energy needs for cooking and heating, and for a wide variety of NWFPs (Neumann and Hirsch 2000), and that the poor frequently depend on their collection as an 'employment of last resort' (Angelsen and Wunder 2003). Regardless of the real and potential importance of NWFPs, national institutions are not carrying out standard monitoring of these resources or assessments of their socio-economic contribution.

Collection and sale of NWFPs can provide employment during slack periods of the agricultural cycle and provide a buffer against climatic risk and household emergencies (Iqbal 1993, Cavendish 2000). In many rural sub-Saharan Africa communities, for example, NWFPs may supply over 50% of a farmer's cash income and provide the health needs for over 80% of the population (FAO 2004).

NWFPs that enter into global trade statistics,

Box 4.2 Gum arabic

Gum arabic is one of the most important NWFPs in Sudan. It is an exudate from *Acacia senegal* tree obtained by bark tapping. Gum arabic production is one of the main activities and source of economic stability in the arid rural areas of Kordofan and Darfur regions of Sudan, where all community members (men, women and children) take part in gum-arabic operations i.e. tapping, collection, sorting, cleaning and marketing. In all, more than five million people work in planting trees, gum production and marketing of gum Arabic in the Sudan.

Over the years traditional farmers in the Sudanese gumbelt have developed a close relationship with, and a comprehensive husbandry system for, this tree (known as *Hashab* in Arabic). In ideal settings a farmer will divide his landholding into four parts, each managed differently for production of Hashab and/or agricultural crops. These four systems include: mature Hashab trees; younger trees among which crops are interplanted; pure cropping where soil fertility is declining and will soon be planted or allowed to regenerate naturally with Hashab; and new cropping areas which had been under trees for 15–20 years (Abdel Nour 2003). This system is currently being modified (less area allocated for cropping with a greater emphasis on Hashab management) to adapt to land shortages and declining rainfall.

Assessment of current and long-term impacts of climate change (2030 and 2060) on gum arabic production has been conducted in Sudan (GoS, 2003). The study indicated that a rise in temperature associated with increased water stress would lower gum arabic production significantly. A southward shift in the natural distribution of this tree species is already being detected and is projected to continue with declining rainfall. It is estimated that this will result in a reduction in gum arabic production, region-wide, of between 25% and 30%.

such as bamboo, rattan, cork, gum arabic, aromatic oils and medicinal plants, can attain high prices in comparison with NWFPs traded on national markets, and contribute to national economic development. Rattan, for example, is one of the most important commercial non-wood forest products in Asia (FAO 2005a). More than 700 million people worldwide trade or use rattan for a variety of purposes. Domestic trade and subsistence use of rattan and rattan products is valued at an estimated USD 3 billion per annum, and another USD 4 billion is generated through international trade, according to assessment made by the International Rattan and Bamboo Network (INBAR 2007).

Different types of NWFPs are used for subsistence and in support of small-scale, household-based enterprises, so their contribution to improving adaptive capacity of local people through diversification of local economies and livelihoods is beginning to be recognized. Moreover, locally traded NWFPs contribute to the fulfilment of daily needs and provide employment and income, mainly for rural people and especially women. In eastern and northern Sudan, for example, Doum (*Hyphaene thebaica*) forests provide a diversity of non-timber forest products of great importance in the rural economy. These products include: sa'af, or fibre from the leaves of young trees used for the manufacture of ropes, baskets and mats; fuelwood and charcoal; and edible nuts, the kernels of which produce 'vegetable ivory'. In addition, the timber from mature trees provides a strong and durable building material for house construction and posts. The manufacture of handicrafts from Doum is predominantly the task of women, thus providing an important source of income at the household level (Abdel Magid 2001).

Potential impacts of climate change on the forest-dependent poor and their subsistence use of wood fuels and NWFPs

The impact of climate change on NWFP is an area that requires greater attention from the research community (Easterling et al. 2007). The site specific nature of both climate change and the provision of NWFP services complicate the understanding of climate change impacts on NWFPs (e.g. Irland et al. 2001). In general, the influences of climate change on these goods and services are more difficult to assess because of high uncertainty regarding ecological effects of climate change, and also because data on the current and projected future demand for these products is incomplete at the global as well as regional and national levels. As Easterling et al. (2007, p. 290) point out 'climate change will substantially impact other services, such as seeds, nuts, hunting, resins, plants used in pharmaceutical and botanical medicine, and in the cosmetics industry; these impacts will also be highly diverse and regionalized'.

Climate change is expected to result, in many regions, in increased frequency and severity of ex-


Matti Nummelin: Collecting fuelwood in Niger


Erkki Oksanen: Picking mushrooms in Finland

Photo 4.2 Climate change is expected to have negative effects on NWFP production in many regions. This can impose additional stresses on people who depend on fuelwood for domestic energy and NWFPs for livelihoods.

treme climate events such as heat stress, droughts and flooding in the coming decades. In particular, it will modify the risks of fires and pest and pathogen outbreaks, with negative consequences for food, fibre and forest production including NWFPs (Easterling et al. 2007). In regions with large forest-dependent populations, particularly in Africa, expected decreases in rainfall, and increased severity and frequency of drought, can be expected to exacerbate current exploitation pressures on forest and expansion of agriculture into forest lands. In these regions, this can be expected to impose additional stresses on people who depend on fuelwood for their domestic energy needs and NWFPs for their livelihoods.

FAO (2005b) points out that smallholder and subsistence farmers, pastoralists and fisherfolk in developing countries may not be able to cope with climate change effectively due to their reduced adaptive capacity and higher climate vulnerability. Eastaugh's (2008) multidisciplinary review of adaptation of forests to climate change found that climate change is expected to impact heavily forest-dwelling communities with no other source of sustenance. The lack of support infrastructure and effective governance system can further increase vulnerability (Adger 1999, Adger et al. 2003, Brockington 2007). This review also highlighted the current research gaps in this area such as: socio-economic effects of climate-change impacts on subsistence lifestyles of forest-dependent communities and the role of forest in adaptation responses within different sectors and regions. Other important research gaps, identified by the 4th IPCC assessment report, include the integrated assessment of climate-change impacts on ecosystem services including on food, fibre, forestry and fisheries, and the relationship between biodiversity and the resilience of ecosystem services at a scale relevant to human well-being (IPCC 2007).

Contribution of NWFPs to Climate Change Adaptation

The sustainable management of forests and trees outside forests for non-timber forest products and benefits presents a range of potential adaptation options, particularly for rural people in developing countries. In semi-arid regions trees not only improve natural rangelands but also provide browse, which is often the only fodder available at critical times of the dry season and during drought years.

Traditional forest-management practices for the production of different types of NWFPs such as fruits, medicine, gums and honey exist in many forest-dependent communities worldwide. The revival and further development of this local knowledge and management practices for sustainable production of NWFPs may represent an important element in the adaptation responses of forest-dependent people to climate change, although the rich indigenous knowledge and associated social institutions and governance structures that support these local practices are disappearing in many regions, as discussed below in sub-chapter 4.5 and in Chapter 5 (sub-chapter 5.1.2). Moreover, such knowledge may be critical for the development of effective strategies for coping with anticipated changes in forest productivity and frequency of disturbances. For example, traditional approaches, combined with insights from forest science, could be used to develop new planting schemes: afforestation, reforestation and degraded land rehabilitation and forest landscape restoration programmes using tree species and varieties that are both adapted to anticipated climatic conditions and are valued by local communities; agroforestry systems that include valued tree and plant species which may become increasingly rare in natural forests due to climate-induced changes in forest structure; and domestication of high-value medicinal plants or other NWFPs on farms and in home gardens (Sampson et al. 2000, Parrotta 2002). Moreover, Carmenza et al. (2005) highlighted that the promotion of agroforestry systems as Clean Development Mechanism (CDM) projects can result in additional positive impacts, including increased food security or diversification of farmer incomes through production and sale of NWFPs.

4.3 Regulating Services

4.3.1 Hydrological Regulation and Water Quality

Among the key forest ecosystem services which are expected to be affected by climate change are those related to hydrological regulation and water quality. These include, among others: the regulation of run-off and river discharge; the maintenance or improvement of water quality through forest filtering and retention of freshwater for consumptive use; buffering against coastal damage by tropical storms and tsunamis (see Box 4.3 on mangrove forests).

As discussed in Chapter 3, the projected future hydrological impacts of climate change on forests, as well as the opportunities and vulnerabilities which these changes present, are highly variable both between and among the world forest domains. Here we consider the socio-economic implications of these forest impacts, and climate change-induced land-use changes that will affect the capacity of forested landscapes to provide users with adequate supplies of fresh water.

Changes in water availability may be influenced by the changes in terrestrial freshwater systems likely to be affected by climate change (Box 4.4). These may in turn be exacerbated by changes in land-use patterns (Brouwer and Falkernmark 1989). Both extremes of very wet and dry conditions predicted for water availability (IPCC 2007, see also Chapter 3) have major socio-economic implications on human well-being and land-use change patterns (e.g. agriculture, urban activities, waste water disposal), which may place further pressure on forests (through their conversion and/or degradation) and negatively affect their capacity to provide key regulating services.

Climate change impacts on water and soil resource are likely to increase existing socio-economic vulnerabilities and adversely affect livelihoods and national development plans, especially in developing countries. At present, soil erosion and extreme weather events (floods and droughts) that affect water availability and quality present major global environmental challenges (OMAFRA 2003, Pimentel et al. 1995, Sophocleous 2004); their socio-economic impacts are unevenly distributed across the world, with greater severity in poorer and more vulnerable regions. Rapid demographic changes in most regions are already increasing demand for water resources and new lands for agricultural production which climate change will, in many regions, only exacerbate (Rogers 1994, Vörösmarty et al. 2000). It is estimated that developing countries will require an additional 120 million ha of land for crops and an expansion of irrigated areas by 40 million ha in the next 30 years requiring 14% increase in extracted water from surface and groundwater resources (Williams et al. 2004).

Under rain-fed agricultural systems that predominate in developing countries, decreased water availability in drought-prone regions may further limit agricultural productivity and encourage changes in land use, including agricultural expansion and forest conversion. The current increasing demand for water in rain-fed agricultural production systems – which account for an estimated 60–70% of global crop production (International Rivers Network 2006) – has in many regions resulted in significant losses of forest hydrological services as a consequence of deforestation of riparian and upland watershed

Box 4.3 Coastal mangroves

Coastal mangroves are an example of a widely utilized forest resource that also provides critical regulating services. They provide multiple provisioning and regulating ecosystem services, including providing nurseries for important fish species and in regulating and protecting coastal areas from floods and coastal storm surges. These ecosystem services are highly valued in the tropical coastal regions, yet mangrove areas have been in decline in the past half century (Alongi 2008).

Coastal storms are projected to increase in most regions of the world under all scenarios of climate change, and impacts will be closely associated with sea level rises of 3–4 mm yr^{-1} (IPCC 2007). With increasing erosion rates and increased frequency or intensity of storms in the tropics, the coastal protection function of mangroves will become more critical over time. But mangrove forests are themselves vulnerable to these impacts: their ability to adapt successfully depends on accretion rates relative to sea level, and while there appears to have been adaptation to sea level rises observed to date, such adaptation will become increasingly difficult at higher rates of rise and with increasing other pressures on mangroves for conversion and lack of space for landward migration (Alongi 2008). Since the IPCC reports in 2007, there has been some evidence from global assessments suggesting that observed and projected sea level rises may in fact exceed those reported in IPCC (Hansen 2007, Rahmstorf 2007), which would exacerbate the vulnerability of mangroves.

The coastal protection function of mangroves is well documented (Walters et al. 2008, Sathirathai and Barbier 2001, Barbier 2006, Tri et al. 1998) and quantified in terms of its economic contribution to well-being. Walters et al (2008) review estimates of the economic value of this protection function ranging from USD120 per household to USD 3 700 and USD 4 700 per hectare of mangrove, depending on the method of estimation (Badola and Hussain 2005, Sathirathai and Barbier 2001, Costanza et al. 1989). While the physical principles have been quantified to show that mangrove forests can attenuate wave energy (Quartel et al. 2007), the efficiency of this energy absorption and the extent to which mangroves can reduce coastal erosion is strongly dependent on physical properties and vegetation dynamics. In areas such as Vietnam, where previous deforestation has occurred, there have been attempts at reforestation, particularly to provide regulating services of coastal protection (IFRC 2002). The Red Cross estimates that planting 12 000 hectares of mangroves reduced the cost of maintaining sea dikes that protect the coast by USD 7.3 million per year. Replanted mangroves provide multiple functions and hence can be justified in local livelihood terms even without the important benefits of coastal protection regulation (Tri et al. 1998, Bosire et al. 2008).

areas (Rockström et al. 2007). This in turn jeopardizes the quantity, flow rates, sedimentation and water quality, thereby affecting other development initiatives such as irrigation schemes for agriculture and hydropower supply. In drought-prone regions, anticipated reductions in water availability resulting from climate-change impacts may encourage prompt human (and animal) migration away from the most severely affected areas towards more favourable areas, and thereby increase potential for conflicts over land and water resources, including between humans and wildlife. Such migration of people would exacerbate land conversion for new settlements and livelihood resources mostly at the expense of forest land. Unfortunately, in spite of these close land-water interactions and the implications of climate change, conventional approaches to natural resources management generally address land and water separately (Falkenmark and Lundqvist 1997).

In addition to the expected impacts of climate change on forests' capacity to provide adequate water resources for agriculture, their effects on public health, particularly for the poor, may be severe. Water available during extreme climate events of drought or floods is often of poor quality and is linked to a range of health problems such as diarrhoea, intestinal worms and trachoma. The burden of obtaining safe drinking water and sufficient water for proper sanitation and hygiene is more profound for the poor who very often live in degraded environments and who are predominantly women and children. Today, 20% of the total occurrence of disease in the developing world, and 34% in sub-Saharan Africa, is associated with environmental degradation; lack of access to safe, affordable water and sanitation constitute the major threat to health in these countries. Forest loss can contribute directly to the severity of these health problems through disruption of the water cycle and increased soil erosion, as well as indirectly – though very significantly – through its effects on local and global climate change, which in turn can have a profound effect on the survival and spread of disease pathogens (World Bank (2001). In developing countries, drought has severe health

Box 4.4 Climate-change projections and water risks (IPCC 2007)

- The impacts of climate change on freshwater systems and their management are mainly due to observed and projected increases in temperature, sea level and precipitation variability (very high confidence).
- Increased precipitation intensity and variability is projected to increase the risks of flooding and drought in many areas (high confidence).
- Semi-arid areas and arid areas are particularly exposed to the impacts of climate change on freshwater (high confidence).
- Efforts to offset the decline in surface water will be hampered by considerable decrease in groundwater recharge (high confidence).
- Vulnerability will be exacerbated by rapid increase in population and water demand (very high confidence).
- Higher water temperatures, increased precipitation intensity, and long periods of low flows exacerbate many form of pollution, with impacts on ecosystems, human health, water-system reliability and operating costs (high confidence).
- The negative effects of climate change on freshwater systems outweigh its benefits (high confidence).

For an explanation of the confidence levels see sub-chapter 1.3.5.

impacts, with widespread crop failure and food shortages resulting in famine. Further, drought conditions can increase the potential for forest fires, which, in turn, can cause loss of life or respiratory distress due to poor air quality, as well as emotional and psychological stresses related to mass evacuations which can accompany both large-scale forest fires and drought-induced famines.

4.3.2 Human Health and Well-Being

Changes in the climate are expected to lead to significant changes in forested landscape structure and forest biodiversity in all forest domains, as discussed in Chapters 2 and 3 of this report. These changes may have significant implications for human health in many forest regions, particularly in tropical and subtropical regions, which should be a cause for concern.

The projected increases in the frequency and intensity of forest fires in many parts of the world will have clear impacts on human health if not prevented or mitigated. Colfer (2001) describes the dismaying results of the 1997–98 forest fires in East Kalimantan following a serious El Niño event. Climate change specialists predict that such events will be more frequent and more intense in the future. More generally WHO (2002) reported that 200 million people in Brunei Darussalam, Indonesia, Malaysia, Philippines, Singapore and Thailand were affected by these same fires. Pneumonia cases increased from 1.5 to 25 times in Southeast Kalimantan, Indonesia, and the number of respiratory diseases increased 2- to 3-fold in Malaysia. Vegetation fires seriously increase the risk of acute respiratory infections, which are already a major killer of young children. The adverse health implications of breathing smoke and other air pollutants have been clearly demonstrated by various researchers (e.g. Smith 2008, Warwick and Doig 2004).

Health professionals, such as Haines et al. (2006), note additional potential effects of climate change: extremes of temperature and rainfall (heat waves, floods and droughts) can lead to hunger and malnutrition, environmental refugees and resulting mental disorders from such catastrophes. Changes in temperature and rainfall may in turn change the distribution of disease vectors; particularly worrisome in forested areas are malaria, dengue and diarrhoea (discussed further below). Sea level rise can threaten low-lying coastal forest populations, particularly where economic conditions do not allow adequate control measures.

Gaining an understanding of the disease implications of climate change in forested areas is particularly difficult, because much of the literature on disease does not specify whether the area is forested or not. Of those diseases that are common in forests and projected to increase with climate change, the most thoroughly studied is malaria. While the number of studies has been increasing over time, there is no broad scientific consensus regarding the likely future impacts of climate change on malaria in forested regions (cf. Matola et al. 1987, Hay et al. 2002, Sheil, in Colfer et al. 2006, Zhou et al. 2004). Haggett (1994) anticipates the health implications of climate change linked to expansion of tropical organisms – many from forested regions – into temperate zones, as do Patz and Wolfe (2002), COHAB2 (2008) and others. Mayer (2000) discusses various possible health implications of warmer temperatures, including an estimate that the population at risk of developing malaria could rise to 2.5 billion people under some temperature scenarios. In explaining the re-emergence of epidemic *Plasmodium falciparum* malaria in East African highlands, these authors focus on human population increase and movement (including the presence of people without functional immunity to local strains – a very common problem in forested regions), land-use change and temperature variability as the important factors. They note that human mortality is increased by drug resistance, inadequate access to drugs, failure to seek treatment in a timely manner and HIV infection.

Russell (1998), although concerned about the implications of global warming for certain arbo-viruses, also does not consider the panic in some quarters about the increasing incidence of malaria to be warranted. Specific ailments he anticipates increasing under conditions of global warming, and which he discusses in some detail for northern (tropical) Australia, include Murray Valley encephalitis and Kunjin viruses, with the arthritides Ross River and Barmah Forest viruses causing more infections. He concludes by noting that risk of increased transmission will vary by locality, vector, host and human factors.

Graczyk (2002) emphasizes the likely climate-related changes in zoonotic diseases more generally, anticipating an increase in vector-borne diseases with global warming (see Gonzalez et al. 2008 for a recent, complex description of forest-disease-wildlife interactions). Several authors (WHO 2007, Shea and the Committee on Environmental Health 2007) emphasize the likely increase in diarrhoea, which is already a major killer of children in the forests of developing countries. They anticipate that increased temperatures will lead to greater incidence of the disease.

Climate-induced changes in the forest landscapes can have effects, particularly on the cultures of those people most dependent on the natural environment (e.g. indigenous and forest peoples). All peoples' mental health is related to the integrity of the cultural systems of which they are a part, and many cultural systems are intimately bound up with the forests (e.g. Lewis 2005, Dounias and Colfer 2008, Gómez 2008). Climate change may induce fundamental changes that can have debilitating effects on these cultural systems (cf. van Haaften's [2002] writings on the psychological effects of Sahelian crises on the victims). Some researchers also predict increases in violence as a result of uncertainties and scarcities that derive from climatic changes (cf. Richards 1996, who documents the impacts of Sierra Leone's wars on its youth).

The predicted alterations of forest landscape and forest biodiversity as a result of climate change may reduce access to forest products – forest foods, forest medicines, fibres, timber and other NWFPs. Such losses can also affect people's health directly, via lower medicinal plant availability, or indirectly, via loss of potential marketed goods and, over time, loss of indigenous knowledge and unique cultural uses of such products. Many of the foods that people obtain from wild sources (anticipated to be under increasing threats) have higher nutritional value than more familiar agricultural products (see e.g. Vinceti et al. 2008). An interdisciplinary group looking at the links between food/nutrition and biodiversity also noted the additional robustness of native species and wild foods, as well as their cultural importance (COHAB2 2008).


John Parrotta: Traditional medicines, India

Photo 4.3 Climate change may reduce access to traditional medicines derived from forest plants and animals. This can have direct health effects on people relying on such medicines or indirect effects through the loss of marketable goods, and over time, loss in indigenous knowledge on uses of such products.

Forest biodiversity losses are widely anticipated results of climate change, which will affect forest-dependent people's access to food, medicine and other forest products, although Jutro (1991) predicted that greater changes will occur in high latitudes than in the tropics. The implications for forest-derived foods, medicines and local people are likely to be complex and severe, but remain difficult to predict precisely.

To summarize, as with many climate-change issues, the uncertainties with respect to its impact on forests in relation to human health and well-being outweigh the certainties. However, there is clearly significant cause for concern and for increased global attention to developing ways to anticipate and adapt to the harmful health effects of the coming changes. Better monitoring of climate-change impact on human health and well-being and more effective involvement of forest communities supported by their local governments will be needed in anticipating, monitoring and solving these problems.

4.4 Cultural Services

4.4.1 Spiritual and Cultural Values

Forests provide a wide range of benefits beyond those related to production and regulating services. According to the definitions for FRA 2005 (FAO 2005b), social services provided by forests include recreation, tourism, education and conservation of sites with cultural or spiritual importance. The area of forests designated for social services is an indication of the extent to which countries and forest managers are actively considering these services as part of the benefits that forests provide. In Europe, for example, nearly three-quarters of the forest area is managed to provide social services, often in combination with other management objectives (FAO 2005b). The social functions of forests are often more difficult to measure and vary to a great extent among countries, depending on their level of development and traditions (FAO 2005a).

Mature forests and old trees have strong cultural and spiritual value in many parts of the world. Several writers have made the analogy between the individual, cultural and social characteristics of trees and people. Rolston (1988) refers to the forest as a religious resource and compares forests to places of worship (i.e. cathedrals). The spiritual-religious values of wilderness have long been noted. Societies most closely entwined with forests tend to regard them with a healthy respect, awe at their splendour and majesty, sometimes dread and fear of the powerful spirits that lurk within them (Laird 2004). In rural areas in Africa, old trees represent social clubs where community leaders meet with their people to discuss important livelihood issues; sometimes trees act as courtyards where villagers meet to solve their local conflicts and disputes. These cultural and spiritual values associated with forests – and trees outside forests – underlines the importance of taking the social dimension of climate change into consideration, particularly where changes in forest structure and species composition are projected as a result of climate change and its associated impacts (changes in natural disturbance regimes – i.e. fire, pests and diseases, wind damage). A more complete understanding of the relationship between people and forests is needed, so that the potential effects of climate change on the cultural services that forests provide can be recognized and taken into consideration in the development of adaptation responses to minimize the negative social and cultural impacts of these changes.

4.4.2 Recreation and Eco-Tourism

The Third and Fourth Assessment Reports of the Intergovernmental Panel on Climate Change both concluded that compared to research in market sectors like timber and agriculture, relatively little work had been done to examine the effects of climate change on recreation (Gitay et al. 2002, Easterling et al. 2007). Recent reports by the US Climate Change Science Program (Sussman et al. 2008), the Finnish Environment Institute (Sievänen et al. 2005) and Hamilton and Tol (2007) come to similar conclusions, although these studies do indicate that the research area is growing and more studies are emerging

It is quite clear, given the large number of days individuals spend in outdoor recreation (e.g. Cordell et al. 1999), that the impacts of climate change could be substantial. However, most studies examine impacts on specific activities (e.g. skiing or fishing), only some of which need to occur in forests. For example, Breiling and Charamza (1999) found that with a temperatures increase of 2ºC, high-altitude ski areas would not necessarily lose recreational visits, but low-altitude ski areas could have negative visitation effects. Irland et al. (2001) found that the specific impacts for the ski area depended on the specific impacts of climate change on that area. Unfortunately, climate models still have substantial variation with respect to their regional projections of climate change.

With respect to summer recreation, Richardson and Loomis (2004) examined visitation to a national park in the US, and found that under two climate scenarios, visitation would likely increase. The park they considered, Rocky Mountain National Park in Colorado, does include forests, but forests are not the only attraction and it is impossible to separate recreational impacts on forest attributes and other attributes. Their analysis also included an ad-hoc scenario to examine ‘extreme heat’, which suggested that above certain thresholds in temperature, visitation to natural amenities could start to decline.

One interesting study that explicitly considered forests is Layton and Brown (2000), who found that the residents of USA were willing to pay USD 10–100 per month for nature conservation to avoid changes in forest structure and function associated with climate change in the Rocky Mountains of Colorado and maintain its recreational function. As expected, higher payments were associated with more severe climate impacts in forests.

Forest ecosystems in Africa support biodiversity and habitat for plants and wildlife. Eco-tourism which is defined by the International Ecotourism Society (TIES 2008) as: 'responsible travel to natural areas that conserves the environment and improves the well-being of local people' is threatened by climate variability. According to the IPCC (2007) climate change may increase the frequency of flooding, drought and land degradation in Africa, and subsequently reduce biodiversity (one pillar of ecotourism) and the viability of recreation activities and wildlife safaris. More frequent droughts may also increase the pressure on the reserve by pastoralists, which may in turn change the human use of land adjacent to the reserve, on which wildlife in the reserve interacts. Ecotourism has been viewed by many as a viable option for improving rural livelihoods in Africa that could be one possible replacement for farm income. However, there is a great need for research and technology in Africa to assess the impact of climate change on ecotourism, particularly on sensitive ecosystems of high touristic value such as the rainforest of the Congo Basin and mountainous biodiversity (Viner and Agnew 1999).

4.5 Relationship between Governance and Socio-Economic Impacts

4.5.1 Governance

All adaptations to changing ecosystem service availability will involve either actions by individuals changing their forest use, or collective action in changing the rules by which individuals use and consume ecosystems services. Hence adaptation to climate change essentially involves altering and adjusting governance structures. Adaptations will take place in reaction to changes in forest productivity, ecosystem change and changes in the provision of ecosystem services from forests and in anticipation of such changes. This sub-chapter highlights two issues. First, it examines whether inappropriate or absent governance and forest policy environments could amplify or exacerbate climate-change impacts in terms of vulnerability of services and forest-dependent people. Second, this sub-chapter examines the potential for adaptations to policies and governance structures to ameliorate and reduce such risks and vulnerabilities. Specifically it examines how the globally observed trend towards decentralized responsibility for the management of forests directly affects the adaptive capacity of the forest sector to cope with shocks such as climate change. It concludes that the impacts of climate change on forest ecosystem provisioning, regulating and cultural services can be ameliorated by human actions to adapt and manage risks associated with these impacts, but that there are significant barriers to action.

4.5.2 Double Exposure of Socio-Economic Impacts to Climate Change and Inappropriate Governance

It is well established that lack of accountability, unclear property rights and rent-seeking directly affect outcomes such as forest integrity and rates of exploitation. In addition, there is some evidence that the breakdown of governance structures can cause or exacerbate conflict over scarce resources such as forests, and that failures in policy environments are likely to exacerbate the difficulty in adapting forest management to a changing set of climate-related risks. Hence it can be hypothesised that a lack of sustainable forest management and governance structures will exacerbate the socio-economic vulnerabilities identified in this chapter.

Analysis of the causes and consequences of lack of governance and the skewed ownership and control of natural resources often uses cross-national statistical analysis. Mikkelson et al. (2007), for example, show that countries with more unequal distributions of income have experienced greater loss of biodiversity as measured through loss of natural habitat such as forests. It should be noted, however, that some analysts have questioned the validity of the methodologies involved in conducing global regression analysis of deforestation (Kaimowitz and Angelsen 2004). Deacon (1994) and Smith et al. (2003) show similar results for forest cover related to levels of corruption. Mikkelson et al. (2007) argue that vulnerabilities are transmitted through the mechanisms of skewed land ownership and lack of accountability. Continuing trends of unaccountable decision-making are likely to make adaptation to climate change more difficult.

A further consequence of failure of governance structures to promote sustainable forest management is the potential for reductions in forest ecosystem services induced by climate-change impacts to exacerbate conflict and non-cooperation over remaining resources, creating downward spirals of unsustainable resource use and well-being of those dependent on them. The evidence base in this area is relatively weak, especially in the context of forest resources (Nordas and Gledditich, 2007). Yet it can be inferred from research on causes of displacement migration, violent conflict and resource management that climate change may aggravate already existing conflicts in the forest sector, or deepen the conflict between forests for conservation and forests for livelihoods (Fairhead and Leach 1995, Bannon and Collier 2003, McNeely 2003). Hence the vulnerabilities and socio-economic impacts on forests highlighted in this chapter are likely to be exacerbated in situations where forests are over-exploited.

4.5.3 Governance Mechanisms to Reduce Vulnerability

Changes in policy that promote sustainable forest management and the maintenance of forest ecosystem services will at the same time reduce the vulnerability of forest- dependent people. The question remains whether current trends in forest governance can potentially decrease resilience. Current trends, as identified by Agrawal et al. (2008), include 'decentralization of forest management, logging concessions in publicly owned commercially valuable forests, and timber certification, primarily in temperate forests'. These trends are confirmed by work from other authors for cases of forest management in West Africa and South-east Asia (Barr et al. 2001, Ribot 2002, Wollenberg and Kartodiharjo 2002).

According to Ribot et al. (2006), Colfer and Capistrano (2005), Agrawal and Ribot (1999), Tacconi (2007) and others, decentralization has the potential to increase local-level capacities to deal with climate change and related threats. But the empirical evidence on whether these benefits are realised is contested (Ribot et al. 2006, Tacconi et al. 2006, Tacconi 2007). A case study on forest ecosystem goods and services and adaptation from Burkina Faso shows that a decentralized governance system may offer maximum space for adaptation to climate-change impacts due to the potential of governance at the local level. But the use of such space for adaptation is dependent upon individual and organizational experiences – experiences with climate change as the context-related challenge and the experiences with the new roles and responsibilities in a changing institutional environment as a structural challenge (Brockhaus and Kambire 2009). Hence co-management and other decentralization of forest management, while having the potential to reduce vulnerabilities identified in this chapter, face significant barriers in realizing their potential.

4.6 Conclusions

- Despite uncertainties associated with current climate and ecosystem model projections, the associated changes in the provision of forest ecosystem services are expected to be significant in many parts of the world.
- The vulnerability of forest systems is related not just to the direct and indirect impacts of climate change, but also to anthropogenic impacts, particularly land-use change and deforestation, which are likely to be extremely important in many parts of the world. These will present significant social and economic challenges for affected communities and society as a whole, particularly among the forest-dependent poor, who are already highly vulnerable in many countries throughout the world, especially in the tropical and subtropical domains.
- Economic studies of climate change rely on climate and ecological modelling to determine how changes in climate variables influence important ecological drivers of annual timber output. Some of the most important factors that have been modelled to date are: changes in the growth of timber as a result of changing net primary productivity or biomass production; changes in disturbance patterns; changes in the geographic distribution of species. The results of most studies suggest that climate change will increase timber production globally, although output could decline in some regions and during some time periods. While reductions in output or reductions in timber prices will have negative effects on timber producers in some regions, timber consumers will benefit from lower prices.
- Regions that appear most susceptible to climate-change impacts on timber production over the next 50 years are North America, Europe, Australia and New Zealand. Output in North America and Europe could decline in the next 50 years due to climate-induced dieback of existing stocks of timber and lower investments in timber production due to lower prices. These changes, however, are expected to be modest, with output increasing over 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.
- In order to understand better the regional impacts of climate change on timber outputs, it is imperative to build a better understanding of the underlying change in climate. The existing studies show that the results over the first half of this century are most susceptible to the effects of climate-related forest dieback. Anything that has a large effect on accessible stocks in regions that currently produce

a large portion of the world's timber will have large impacts on markets. Thus stronger dieback effects in temperate and boreal regions would lead to larger negative impacts in those regions and globally.

- Non-timber forest products are important sources of income and livelihood security for forest-dependent people, and often provide a 'safety net' for agricultural communities during periods of economic stress due to crop failures that may become more common as a result of climate change. Efforts to promote sustainable management, local processing and marketing of non-timber forest products can help to enhance incomes and buffer agricultural livelihood impacts of climate change.
- Changing forest structure and plant and animal species composition may present opportunities for utilization of new forest species in some regions, but decrease availability of non-timber products for sustenance or commercial use derived from species that will become rarer. Taking advantage of opportunities and reducing vulnerabilities associated with changing availability of non-timber forest products may require new approaches to forest management to sustain their productivity and special measures, such as ex-situ conservation and development of domestication/ cultivation practices for key non-timber forest products, e.g. for high-value tree and other plant species in agricultural, agroforestry and silvo-pastoral systems.
- Potential impacts of climate change on non-wood forest products and other services provided by forests are not well researched. Consequently the contribution of forests to adaptive capacity of local communities are not well understood. More work is needed to generate the information on forest-related adaptation strategies.
- Both extremes of very wet and dry conditions predicted for water availability have major socio-economic implications on human well-being and land-use change patterns (e.g. agriculture, urban activities, waste-water disposal), which may place further pressure on forests (through their conversion and/or degradation) and negatively affect their capacity to provide key regulating services.
- The projected increases in the frequency and intensity of forest fires in many parts of the world will have clear impacts on human health if not prevented or mitigated. The predicted alterations of forest landscape and forest biodiversity as a result of climate change may reduce access to forest products. Such losses can also affect people's health directly, via lower medicinal plant availability, or indirectly, via loss of potential marketed goods and, over time, loss of indigenous knowledge and unique cultural uses of such products.
- Gaining an understanding of the disease implications of climate change in forested areas is particularly difficult, because much of the literature on disease does not specify whether the area is forested or not. However, it is expected that changes in temperature and rainfall will change the distribution of disease vectors; particularly worrisome in forested areas are malaria, dengue and diarrhoea. Sea level rise can threaten low-lying coastal forest populations, particularly where economic conditions do not allow adequate control measures.
- Climate-change impacts on forest can be exacerbated by lack of sustainable forest management and governance structures which in turn will exacerbate the socio-economic vulnerabilities. The highlighted vulnerabilities and socio-economic impacts on forests are likely to be exacerbated in situations where forests are over-exploited. It is argued that vulnerabilities are transmitted through the mechanisms of skewed land ownership and lack of accountability. Continuing trends of unaccountable decision-making is likely to make adaptation to climate change more difficult.
- Failure of governance structures to promote sustainable forest management has the potential for reducing forest ecosystem services induced by climate-change impacts, exacerbate conflict and non-cooperation over remaining resources, and eventually create downward spirals of unsustainable resource use and well-being of those dependent on them. It is likely that climate change can aggravate already existing conflicts in the forest sector, or deepen the conflict between forests for conservation and forests for livelihoods.

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5 Current Adaptation Measures and Policies

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Abstract: As stated in earlier chapters, the possible impacts of climate change on forests and the forest sector are considerable, and many impacts have already been observed. As forest conditions change, there is an inherent need to change management and policy measures to minimise negative impacts and to exploit the benefits derived from climate change. This chapter highlights trends in existing policies and management measures that promote the adaptation of forests to climate change, and barriers to implementation. An investigation into existing policies indicates that they often serve multiple purposes and are not introduced solely in response to climate change; that local forest-related knowledge is an important and under-utilised resource which should be better recognized; that countries have yet to overcome all the barriers to implementing adaptation policies; and that existing policies tend to be reactive rather than proactive and reflect national socio-economic and environmental circumstances.

Keywords: adaptation, management, local knowledge, policy, UNFCCC, national communications, NAPA

5.1 Observations of Human Adaptation to Climate Change

5.1.1 Forest Practices as Adaptations to Climate

Several aspects of contemporary forest management and policy can be viewed as adaptations to climate (Spittlehouse 2005). For example, common practices such as planting trees and harvesting products have been adapted to local climate conditions, including seasonal patterns of temperature and precipitation. However, local forestry practices are often based on an implicit assumption that local climate conditions will not change (Guariguata et al. 2007).

Appendix 5.1 presents selected examples of human adaptations to climate. The examples suggest that adaptation to climate and its impacts on ecosystems must be tailored to local conditions. Options for adaptation vary among geographical regions and forest types. Furthermore, adaptations in commercial forestry operations are very different from those made by communities in developing countries that depend on forests for subsistence.

Most adaptations to local climate conditions serve more than one purpose. For example, people in several developing countries are planting and tending drought- resistant trees with edible fruits to enhance food security and nutrition, reduce erosion and provide an additional source of fuelwood (Appendix 5.1).

Some countries and private companies have made substantial investments in forest genetics research and tree-breeding programmes. These investments have enabled major improvements in the growth rate and disease resistance of planting stock for several tree species (Burdon and Libby 2006, Kanowski and Murray 2008).

Actions that restore and conserve biodiversity are a means of increasing ecosystem resilience to climate change and other stress factors (Tilman 1999, Noss 2001). In many situations, efforts to adapt to climate change and mitigate greenhouse-gas emissions in the forest sector are compatible with efforts to tackle the associated threats of habitat destruction, fragmentation and degradation (Krankina et al. 1997, Williams 2000, Noss 2001).

5.1.2 Local Knowledge and Traditional Adaptation Strategies

In many forest-dependent communities with subsistence economies or in a tenuous transition towards market-based economies, local forest-related knowledge continues to play a vital role in meeting basic livelihood needs. Local knowledge and associated forest management practices have sustained local and indigenous communities throughout the world under changing environmental, social and economic conditions, long before the advent of formal forest science and 'scientific' forest management. Local forest-related knowledge is usually closely linked to traditional land-use practices, local decision-making processes and governance institutions, and beliefs about the relationships between community members and forest environments.

Many forest-dependent communities are well known for their knowledge of the natural world, and often possess keen insights into meteorological phenomena, animal behaviour and forest phenology. Accustomed to inter-annual and longer-term variability in climate, most indigenous and other forest-dependent communities have acquired sufficient knowledge of plant and animal species and their management and use to enable them to cope with changing abundances of preferred species used for food, medicine and other purposes.

Particularly relevant in the context of adaptation to climate change are traditional forest and water management practices aimed at maintaining water quality and conserving scarce water resources. Many of these practices are well known and described in the scientific literature. In semi-arid and arid regions, for example, a wide variety of local technologies have been developed to harvest and conserve scarce water resources in traditional silvopastoral and agroforestry systems (Laureano 2005, Osman-Elasha et al. 2006). In north-eastern India, the soil and vegetation management practices developed over generations by local communities have been shown to enhance soil fertility and minimize erosion losses in shifting cultivation areas (Ramakrishnan 2007).

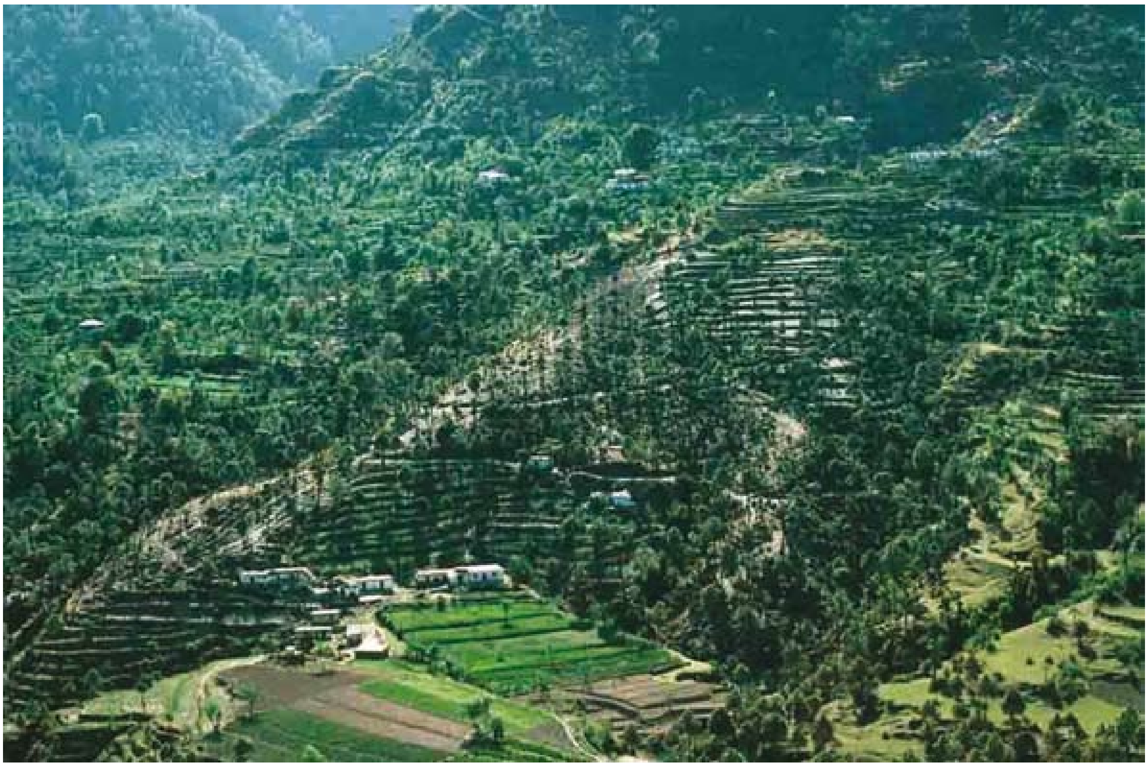
In response to expected climate-induced changes in forest structure and species composition, local knowledge of the uses of a wide range of forest plant and animal species enhances possibilities for meeting forest-dependent peoples' needs by substitution of increasingly rare species with those that may become more abundant. For cultivated forest species, local knowledge and traditional tree and forest management can play a key role in maintaining forest/tree productivity (and food security) in the face of climate change. This has been documented e.g. in Italy, where centuries-old practices for managing chestnut orchards have enabled local communities to cultivate this important woodland food source on sites well beyond the natural climatic limits of the species (Agnoletti 2007).

Although local knowledge represents an important element of adaptive capacity for local and indigenous communities to cope with climate change, it is important to recognize its actual or potential limitations (FAO in press). Such knowledge is rarely codified and often restricted to a few members of local, particularly indigenous, communities, which increases its vulnerability to inter-generational loss. While it has been shown to be dynamic, its capacity to adapt quickly enough to the more dramatic climate-change impacts on forests envisaged for some regions cannot be assumed. Furthermore, local and indigenous knowledge is already disappearing in many parts of the world for a number of reasons.

The expansion of increasingly globalized market economies in previously self-sufficient rural areas, the impact of infrastructure development and greater exposure to mass media, government policies and regulations within and outside the forest sector that restrict access and traditional use of forest resources – these have all contributed to a general erosion of traditional cultures and of associated land and forest management knowledge and practices. They have also contributed to declining interest in traditional lifestyles among the younger generation in these communities. The negative implications of this loss on livelihoods, cultural and biological diversity, and the capacity of forested landscapes to provide ecosystem goods and services remain poorly understood, largely unappreciated and undervalued by policy-makers and the general public in most parts of the world (Cox 2000, IAITPTF 2005).

However, opportunities exist to revitalize local knowledge and develop appropriate strategies for adaptation of forest resource management to climate change that combine local and scientific forest knowledge (Kruger 2005). For example, local knowledge can complement formal science in monitoring the effects of climate change (Vlassova 2002). The translation of local forest knowledge into the language of formal forest science is an important step towards adaptation and application of local forest knowledge to new or changing environmental, social and economic contexts. It may find important applications in forest rehabilitation, restoration and adaptive management of forests in the face of climate change (Berkes et al. 2000, Parrotta and Agnoletti 2007).

Achieving effective synergies between local and scientific forest-related knowledge to deal with the impacts of climate change on forests will require broader participation of local and indigenous communities, and a better understanding by decision-makers and the scientific community of the knowledge and wisdom of forest-dependent communities on



John Parrotta: Himachel Pradesh, India

Photo 5.1 Local forest knowledge can contribute to forest rehabilitation, restoration and sustainable land management in the face of climate change.

issues related to forest landscape conservation and management. Interdisciplinary, participatory research and development may play a key role in this process, and help to reverse the ongoing erosion of local forest-related knowledge, practices and social institutions that threaten indigenous cultures and knowledge systems worldwide, as well as their capacity to adapt to climate-change impacts on forest ecosystems.

5.1.3 Barriers to More Effective Adaptation

Forest-sector responses to extreme climate events and longer-term changes in climate patterns have been reactive in most cases. Efforts to encourage proactive adaptation must address forthrightly the reality that stakeholders in the forest sector have diverse values and interests that can impede efforts to reach consensus on goals for adaptation (Spittlehouse 2005, Adger et al. forthcoming). The values that underpin adaptation decisions become more diverse and complex as one moves from smaller to larger scales with increasing numbers of stakeholders. Adaptation strategies must give explicit attention to normative issues such as trade-offs among competing values and interests, distribution of costs among stakeholders, and potential for changing preferences and unintended consequences over time.

Proactive adaptation strategies must also deal explicitly with uncertainty in projections of future climate changes and their impacts. Uncertainty per se should not necessarily be a reason for inaction (Dessai and Hulme 2004). However, climate- change projections are perceived by many forest managers as too uncertain to support long-term and potentially costly decisions that may be difficult to reverse. Similarly, uncertainty over future policy developments may also constrain action. In Sweden, for example, uncertainty exists over the future of certain conservation and social policies that may expand areas in which logging is prohibited. This can create uncertainty among stakeholders. They can feel that they have no control over the future of their forestry operations and thus no incentive to plan for adapting to uncertain climate changes (Keskitalo 2008).

Arvai et al. (2006) argue that principles of 'Adaptive Management' (Holling 1978, Walters 1986) should be applied to the challenge of addressing complexity and uncertainty in climate policy. In brief, 'Adaptive Management' involves simultaneous implementation of alternative treatments (e.g. adaptation measures and policies) in different locations and comparison of results to test hypotheses about the behaviour of complex systems.

The potential for climate change to alter a system's response to treatments may be an important consideration in future applications of Adaptive Management in the forest sector. For example, current theory and practice in forest biodiversity conservation often emphasize minimization of human influence on forest reserves. More active management strategies may be necessary to conserve important elements of biodiversity in some wilderness and natural areas in regions that experience rapid and severe changes in climate.

Finance is a further barrier to implementing adaptation actions in the forest sector. Climate change is one more issue facing decision-makers and competing for resources. When public or private authorities undertake adaptation measures, they will need reasonable estimates of costs and benefits to justify their actions. At present, most adaptation proposals are lacking such estimates, although this is an area currently receiving considerable attention (UNFCCC 2007, Watkiss et al. 2007, Agrawala and Frankhauser 2008).

Keskitalo (2008) noted that socio-economic and political conditions have significant influences on vulnerability and adaptive capacity. Current conditions and near-term choices about development and adaptation will have important influences on future adaptation options.

5.2 Existing Policies for Adaptation

5.2.1 Introduction

Policy programmes and instruments concerning the adaptation of forests to the predicted impacts of climate change aim at enabling forest owners and forest managers to take appropriate actions in time to ensure sustainable forest management (SFM) under the changed conditions of global warming. The information presented in the following section indicates existing trends in management and policies for promoting the adaptation of forests and the forest sector to climate change. The information is based in post-2004 national communications (NCs) and National Adaptation Programmes of Action (NAPAs) produced for the UNFCCC (United Nations Framework Convention on Climate Change) (Roberts 2008). These documents were selected for analysis as they are representative sources of information and structured within standard frameworks. Although this allows for indicative comparison of existing policies, the NCs and NAPAs provide insufficient information to assess the impacts or effectiveness of policies and management measures. Further research at the national level is needed to determine this.

No attempt was made to delineate adaptation from mitigation when the information was insufficient or when the delineation was not practical. Policy promoting sustainable forest management, for example, can assist in mitigating climate change through increased sequestration and storage of carbon, while autonomously promoting the adaptation of forests through increasing forests' natural adaptive potential.

The following information is delineated into the tropical, subtropical, temperate and boreal domains in accordance with the classification of the Global Forest Resources Assessment (FAO 2001). For each forest domain the management, policy and policy instrument options for promoting the adaptation of forests and the forest sector to climate change is presented. In the following abridged version, the policy instruments reported in the NCs and NAPAs are divided into regulatory (based on state power), economic (based on money) and informational tools (based on information), outlining the key policy trends for each domain.

*5.2.2 Tropical Domain**

Forest Management Measures: The application of community-based forest management aimed at promoting afforestation and the conservation of land, water and timber resources is commonly promoted within national reports. For example, India reports on short-term rotation species and management practices to increase the resilience of forests to climate change. SFM is also reported as a method of increasing the resilience of forests to climate change. Changes in forest management, such as harvesting and planting dates, and utilization of thinning are reported as further possible methods of adapting to climate change.

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* Tropical Annex I countries include: Australia and the United States of America, with Non-Annex I countries being Brazil, Cameroon, Fiji, Gabon, Guinea-Bissau, India, Madagascar, Mexico, Nepal, Rwanda, Sao Tome and Principe, Saudi Arabia, Sierra Leone, Solomon Islands, Suriname, Tonga, Turkmenistan, United Arab Emirates, Venezuela. Countries which produced a NAPA include: Bangladesh, Benin, Bhutan, Burkina Faso, Burundi, Cambodia, Cape Verde, Comoros, Democratic Republic of Congo, Djibouti, Eritrea, Guinea, Guinea-Bissau, Haiti, Kiribati, Madagascar, Malawi, Mali, Mauritania, Niger, Rwanda, Samoa, Sao Tome and Principe, Senegal, Sudan, Tanzania, Tuvalu, Vanuatu, Zambia.

Policies for Adaptation and Instruments

Many countries located in the tropical domain report a restricted ability to adapt to climate change due to limited financial resources. Overall, the adaptation options for the domain focus on reducing the anthropogenic stresses on forests through the use of regulatory, economic and informational instruments.

Regulatory instruments: Forest conservation, in the form of formal protection areas and SFM, are highlighted as adaptation options to climate change. Regulations in place for the enforcement of such actions are often associated with national forest programmes (NFPs) or equivalents. However, throughout the tropical domain the reports mention problems with the implementation of regulatory policy, such as protective areas, due to a lack of resources for the enforcement of such measures. As a result illegal anthropogenic practices and exceeding of cutting concessions continue to degrade protected areas. Unsuitable policy coupled with insufficient means for enforcement is reported to limit efforts to combat deforestation. Consequently, institutional strengthening of departments and bodies concerned with forest management, research and protection, including their ability to enforce legislation, is identified as a necessary step for decreasing the vulnerability of forest to climate change. This is reported to be achieved through increasing the human and technological resources.

Economic instruments: The utilization of financial instruments for adaptation to climate change was comparatively limited within the tropical domain. Community- based and national afforestation projects have been initiated throughout the tropical domain. Despite these efforts, it is also reported that the level of afforestation is insufficient to compensate the level of deforestation. A possible solution to deficient law enforcement is alignment of financing mechanisms toward the 'protector receives' principle, where those who protect a resource of communal interest are rewarded. This is reported to be a suitable mechanism for environmental protection in poverty-stricken regions as financially poorer communities are more likely to respond to financial incentives (rewards) rather than disincentives (fines).

Financial incentives for SFM, reforestation and changes to non-wood-based fuels (including changes to fossil fuels) are also mentioned as a means of promoting adaptation. However it is also noted that a lack of financial resources may impede the utilization of economic instruments.

Informational instruments: In addition to NFPs, capacity building through the dissemination of information (via training, research, projects, etc.) regarding future risks and potential solutions is frequently mentioned throughout NAPAs and NCs. A limiting factor mentioned in the reports is insufficient data for baseline information regarding forests. As a consequence, the establishment of monitoring programmes to determine the current situation of forests and further research into future projections of climate change, including extreme events, are reported as important measures for adaptation. The need for the incorporation of climate change into short- to long-term planning at all levels of decision-making, from forest-management plans to the long-term policy-making process, is also identified within the NCs and NAPAs.

*5.2.3 Subtropical Domain**

Forest Management Measures: The predicted poleward migration of tree species (*see chapters 2 and 3*) is reported to require assistance by forest management. This may include measures such as the establishment of migration corridors connecting nature reserves. It is also noted that forest management should focus on reducing stress from external sources, such as extreme events and disturbances. Some additional management options reported for promoting adaptation are: high-quality genetic selection or selection of trees from specific varieties/origins; promotion of mixed-species forests; decrease of the area of monocultures; and reducing the threats of pests and diseases.

Policies for Adaptation and Instruments

Examples of policies aimed at promoting the adaptation of subtropical forests to the predicted impacts of climate change tended largely to reflect the need to address the vulnerability to desertification and increase the natural resilience of forests by improving environmental conditions and reducing external stresses.

Regulatory instruments: Implemented regulatory instruments define who is responsible for the incorporation of adaptation into local planning. As with the tropical domain, forest policies such as Forest Acts or equivalents are used to promote SFM.

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* Sub-tropical countries include Annex I countries which are contained within this region and have produced a NC include: Australia, Croatia, France, Greece, Italy, Japan, Monaco, New Zealand, Portugal, Turkey and United States of America. Non-Annex I countries include: Argentina, Bahrain, Brazil, China, Mexico, Saudi Arabia, Turkmenistan and Uruguay, and countries which developed a NAPA include: Lesotho and Maldives.

Geoff Roberts: Temperate forest in Czech Republic

Photo 5.2 Examples of policies promoting the adaptation of forests to climate change introduced in the temperate domain are often reactive and form parts of National Forest Programmes or equivalents.

Afforestation, fire prevention and improvements in forest health are measures taken to reduce the vulnerability to desertification threatening many countries in the domain.

Economic instruments: Economic instruments aimed at improving the environmental and forest conditions are being applied. In Australia for example, tax incentives (deductions) for the expansion of plantations and grants for environmental plantings have been implemented. Similarly, New Zealand has a local afforestation programme which utilizes financial incentives. Although these tools are not specifically aimed at increasing the adaptive capacity of forests or adapting to climate change, they contribute to it through reducing stresses on existing forests and improving environmental conditions.

Informational instruments: The dissemination of information on the impacts of climate change on forests, such as the increased susceptibility to fire events, is seen as critical for anticipatory measures. National Forest Acts and a National Adaptation Strategy or equivalents are commonly used for dissemination of information pertaining to adaptation to climate change.

Examples of the use of information tools are given in the Italian NC which reports that through the introduction of a fire education programme, the number of anthropogenic fires could be reduced. Similarly, in Portugal, leaflets have been distributed to the general public on methods to reduce the impact of drought, fire and heat waves, although this is not specific to the forest sector.

*5.2.4 Temperate Domain**

Forest Management Measures: The management techniques outlined in the NCs concern mainly the formation of more stable forests in the face of climate change. Near-nature forest management and a move away from monocultures toward mixed forest types, in terms of both species and age classes, are advocated. In addition, natural or imitated natural regeneration is indicated as a method of maintaining genetic diversity, and subsequently reducing vulnerability. For management against extreme disturbances, improvements in fire detection and suppression techniques are recommended, as well as methods for combating pests and diseases. It is reported that through stricter quarantine and sanitary management, the impact of insects and diseases can be minimized.

As with the subtropical domain, reports state that the establishment of migration corridors between forest reserves may aid in the autonomous

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* Countries in the temperate domain which have submitted a NC are Australia, Austria, Belarus, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Japan, Latvia, Liechtenstein, Lithuania, Netherlands, New Zealand, Poland, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Ukraine, United Kingdom and the United States of America. Non-Annex I countries are China and Turkmenistan.

colonization and migration of species in response to climate change.

Policies for Adaptation and Instruments

The adaptation policy options identified in the NCs are largely concerned with increasing the resilience of forests to climate change, through forest expansion, SFM and forest protection, although these are often secondary impacts of the policy, with mitigation being the primary objective. The policies that were introduced concerning adaptation of forests and the forest sector are often reactive and form parts of NFPs or rural development programmes.

Regulatory instruments: Strengthening national forest laws or equivalent processes aiming at SFM, and subsequently adaptation, is commonly referred to throughout the NCs. This includes the protection of forests and forest genetics as well as the setting of performance guidelines for forest management. Also reported is in-situ conservation and protective legislation against deforestation.

Economic instruments: Economic instruments, such as grants, subsidies and compensatory payments are used to promote afforestation, changes in species composition and recovery from extreme disturbances. Voluntary forest certification systems such as the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification schemes (PEFC) are also used for providing financial incentives for SFM, and subsequently adaptation.

Informational instruments: NFPs are a common mechanism for promoting the adaptation of forests to climate change. They provide foresight to the future climatic conditions and planned as well as reactive adaptation. Furthermore, dissemination of information concerning the likely impacts of climate change, the economic and financial implications of adaptation measures, as well as guidelines for adaptation and assessing climate-change impacts and adaptation options, are portrayed as invaluable instruments when dealing with climate change. National monitoring and research programmes targeting the impacts of climate change support the national strategies. Mapping of areas and forest types which are sensitive to climate change and carrying out risk assessments are also reported as steps to promote adaptation.

*5.2.5 Boreal Domain**

Forest Management Measures: As with other domains, the establishment of migration corridors from south to north between fragmented landscapes is reported as a means of aiding the migration of species responding to changed climatic conditions. Changing the species composition to form more stable forests is reported as a management option; an example is changing the species in southern Finland from spruce and pine to birch. In a similar context, Sweden has been working on a breeding programme aimed at developing trees that would be adapted to the projected future climate. Various provinces of Canada have introduced climate-change programmes for combating the increase in major disturbances, in particular to fire and insects. Throughout Canada the introduction of prescribed burning is viewed as a viable option for reducing the risk of large-scale fire events, which are predicted to increase under the changed climatic conditions.

To adapt to shorter winter harvesting periods as well as soft soils and roads, new harvesting techniques that better suit new conditions need to be developed. It is also reported that in some regions increasing population levels of large game, in particular moose, will increase the need for game management.

Policies for Adaptation and Instruments

As implied in the tropical domain, a country's ability to adapt to climate change will depend largely on financial, human and institutional capacities; thus the more developed regions may adapt more easily than regions within less developed countries. As the boreal domain consists of comparatively few countries with well- developed economies, there are good grounds for adaptation. However, there was limited evidence of existing policies to promote the adaptation of forests to climate change, with the exception of informational instruments. Finland reports that past research efforts have focused primarily on the impacts of climate change on forests and the forest sector, with a relatively low level of research into adaptations. It also states that a lead time of 10 to 100 years is required for planning and implementing adaptive strategies for forests.

Informational instruments: Informational instruments prevail in promoting adaptation in the boreal region. It is reported that the main aims for policy

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* Countries which have submitted a NC include: Canada, Finland, Iceland, Norway, Russia, Sweden and the United States of America.

on adaptation are to: raise awareness of adaptation; facilitate and strengthen capacity for coordinated action on adaptation; incorporate adaptation into policy and operations; promote and coordinate research on impacts and adaptation; support knowledge-sharing networks; and provide methods and tools for adaptation planning. Finland has launched a National Adaptation Strategy which also includes forestry. The proposed instruments aim at anticipatory and reactive policies of public administration and the private sector. The individual policies are indicated as immediate (2005–2010), short-term (2010–2030), and long-term (2030–2080). However, there was no information on policy implementation concerning the adaptation of forest to climate change. Under a similar premise, Norway and Canada are reported to be developing a National Adaptation Strategy or equivalent. In addition, Canada has introduced provincial action plans and strategies for reducing the vulnerability to fire, including the introduction of prescribed burning to alter fuel loads in forest. These initiatives have successfully reduced the forest area burned and the occurrence of large-scale forest fires.

5.3 Conclusions

- Adaptation to climate change has started to be incorporated into all levels of governance, from forest management to international forest policy. Often these policies are not adopted solely in response to climate, and may occur in the absence of knowledge about longer-term climate change. They often serve more than one purpose, including food and fuel provision, shelter and minimizing erosion, as well as adapting to changing climatic conditions.
- Local forest-related knowledge, practices and associated social institutions, developed under changing environmental conditions by indigenous and local communities over generations, represent an important source of adaptive capacity for local forest-dependent communities in the face of climate-change impacts on forest ecosystems. Greater recognition of local institutions and the individual actors involved in decision-making processes for planning adaptation may enable successful adaptive forest governance.
- Although local forest-related knowledge is declining in most regions of the world, its importance for strengthening local and indigenous community adaptation to climate change should be recognized, and supportive actions taken to preserve, protect and foster its further development. Equitable collaborative efforts between the holders and users of local knowledge and scientists and forest managers can help to elucidate underlying ecological principles that may enable wider application and further development of local knowledge and associated forest resource management practices to cope with climate-change impacts.
- Overall, the existing policies, as identified in the NCs and NAPAs, reflect the different priorities and circumstances, both environmental and socio-economic, of countries and general conditions of domains. Although there are many similarities, country/domain differences have also led to the formation of contrasting policies. Often, reported adaptation policies are built on existing forest-policy frameworks, reiterating the point that policies are devised not only in response to climate change, but serve multiple purposes. Further research is needed to investigate the effectiveness of these policies.
- Similarities in policies between domains include the use of SFM as a means of adapting to climate change. It is commonly promoted through National Forest Acts or equivalents. However, most NCs and NAPAs fail to identify the more specific policies or specify the necessary changes for adaptation which are embodied in the concept of SFM, rather relying on the generalized term. In a similar context, the existing policies are often attributed to general vulnerability to climate change rather than specifics and tend to be reactive to observed events rather than proactive (anticipatory adaptation). This indicates programme deficits, as there are noted vulnerabilities without corresponding policies. These deficits probably reflect the difficulties in introducing adaptation strategies which meet the diversity of values associated with forests, the potential for changing preferences, actual and potential costs, as well as uncertainty. Although the above mentioned issues pose a significant difficulty, they should not permanently impede efforts to introduce proactive/anticipatory adaptation strategies.

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Appendix 5.1 Examples of adaptations to local climate conditions and variability.

Country	Adaptation
Bangladesh	Cultivation of drought-tolerant fruit trees to diversify household income sources, ensure food security and provide shade and fuelwood (Selvaraju et al. 2006).
Bhutan	Local regulations and community enforcement encourage regeneration of bamboo resources in Bhutan by means of closed seasons (during shooting and young stage); selective harvesting; rotational harvesting; and protecting the sacred groves and areas near water sources (UNFCCC 2008a). The Monpas, a Bhutanese ethnic group, harvest wild vegetables, fruits and tubers from the forest during times of food scarcity due to erratic rainfall. 92% of households depend on forest food during food shortage from January to March (UNFCCC 2008b).
Botswana	Drought-resistant fruit trees are planted around villages. The fruit are vitamin-rich and the trees are able to produce even during drought years, and provide an additional income when traditional crops fail due to poor weather (Boven and Morohashi 2002).
Brazil	Erosion-prone areas near Rio de Janeiro are being reforested in order to control erosion and reduce the associated land-slide and flood risks to the city, particularly the vulnerable squatter settlements (favelas) (Lobo 1998).
Burkina Faso	Afforested areas with Acacia to protect against drought and aridity, and to provide firewood, fodder, tannin, pulpwood, shelterbelts and soil improvement (UNFCCC 2008c).
Canada	Indigenous ecological knowledge has been documented and communicated in Canada with the aim of informing public policy and environmental decision-making in the Hudson Bay bioregion (Boven and Morohashi 2002).
China, Loess Highlands	Reforestation using indigenous species adapted to the local conditions to control erosion and flooding problems. Fruit trees and medicinal herbs are also increasingly cultivated to increase farmers´ incomes (Wu Bin 2005).
El Salvador	Addressing drought problems by reforesting areas with fruit trees (among other measures), to protect soil from erosion caused by water and wind while augmenting the local food supply (Vega 2003).
Grenada	Growing appropriate tree species on cultivated land to reduce vulnerability to hurricanes and to provide various other benefits, including reversal of the deforestation trend (World Agroforestry Centre 2007). Top pruning to strengthen and reduce the height of trees and shrubs so that they are better able to resist hurricanes (OECS 2004).

India	In the Himalayas, where communities are faced with erratic rainfall during spring and summer, farmers have developed agro-forestry practices to ensure food security and additional income, particularly growing cardamom, bamboo groves and fruit trees (Verma 1998).
Jamaica	Alley cropping (the practice of planting trees in rows with food or cash crops between them) is used to reduce the vulnerability of the population and their environment to hurricanes and hurricane-related devastations (Thomas-Hope and Spence 2002, Spence 2005).
Mali	Farmers grow Jatropha plant for fuel and protection from damage from wind and water (Henning 2002).
Senegal	Cultivation of moringa trees that are very drought-resistant and tolerate a wide variety of soil types. They can be used to combat malnutrition by providing enriched food and by treating drinking water (Boven and Morohashi 2002).
Sri Lanka	Agro-forestry practices have been implemented in response to drought and the declining per capita availability of agricultural land (Ranasinghe 2004).
Sweden	Forestry workers have adapted to changes in climate (notably warmer temperatures) by road building and road sanding to combat early thawing (Keskitalo 2008).
Tajikistan	CARE project plants trees to stabilise eroding soils and slopes as protection from erratic rainfall (UNFCCC 2008d).
Tanzania	In the Shinyanga region in the north of Tanzania, traditional practices of conservation have been revived by a government initiative. By encouraging vegetation regeneration and tree planting, ‘ngitili’ has proven to help protect the environment, particularly against drought and aridity, and improve the livelihoods of communities in the region (Barrow 2002).
Thailand	Five-year Action Plan for Mangrove Management in the Gulf of Thailand preserves mangrove forests and promotes sustainable use of mangrove resources. Mangroves provide protection against disasters such as storm surges and are an important coastal protection resource. The programme’s activities include reforesting and maintaining mangroves; providing training to build capacity for community forest management and increase partnerships between the local community, the government and NGOs, and reduce illegal wood harvesting and land cultivation; and to set up Mangrove Protection Zones (UNFCCC 2008e).
Zimbabwe	Deep-rooted trees are used in agro-forestry operation in order to tap more moisture from a lower depth during the dry season, in order to increase the overall productivity of land. Different crop canopies use light efficiently, and the agro-forestry systems return large amounts of nutrients to the soil, as well as provide shelter against wind erosion (Agobia 1999).

6 Management for Adaptation

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Abstract: This chapter develops a framework to explore examples of adaptation options that could be used to ensure that the ecosystem services provided by forests are maintained under future climates. The services are divided into broad areas within which managers can identify specific management goals for individual forests or landscapes. Adaptation options exist for the major forest regions of the world but the scientific basis for these adaptation options and their potential effectiveness varies across regions. Because of the great variation in local conditions, no recommendations can be made that are applicable to an entire domain. The choice of management option will depend on the likely changes occurring in the forest, the management objectives of that forest, its past management history and a range of other factors. Local managers must have sufficient flexibility to choose the most appropriate suite of management options for their conditions. The current failure to implement fully the multi-faceted components of sustainable forest management is likely to limit the ability of forest management to adapt to climate change. Forest managers will need to plan at multiple spatial and temporal scales and will need to adopt adaptive collaborative management as their primary form of management. Careful monitoring and evaluation will be required, with a change in focus from outputs to outcomes.

Keywords: climate change, forest management, forest planning, adaptation, boreal forests, temperate forests, subtropical forests, tropical forests, deforestation, forest degradation, carbon emissions, carbon sinks

■

6.1 Introduction

Forest management has a long history of development through scientific research and through management experience. Management theory and practice continue to evolve as new stresses and threats affect forest dynamics. In this chapter, we identify a number of services associated with sustainable forest management. The provision of these services, as a whole, comprises sustainable forest management (SFM). However, SFM is more a concept than a practice – it represents a target which many managers aspire to, but which few if any have achieved. This does not preclude SFM as an objective: the idea of continuous improvement is one that is common in management, and as applicable in forestry as in any other sector.

How might climate change affect the ecosystem services provided by forests, both directly and indirectly? There are many different possibilities, with some changes (such as changes in the frequency and severity of forest disturbances) affecting multiple services. In relation to the thematic areas of sustainable forest management developed by the United Nations Forum on Forests (UNFF 2004), it is possible to identify a number of broad groups of impacts:

Forest cover: conversion of forests to non-woody energy plantations; accelerated deforestation and forest degradation; increased use of wood for domestic energy.

Biodiversity: alteration of plant and animal distributions; loss of biodiversity; habitat invasions by non-native species; alteration of pollination systems; changes in plant dispersal and regeneration.

Productivity: changes in forest growth and ecosystem biomass; changes in species/site relations; changes in ecosystem nitrogen dynamics.

Health: increased mortality due to climate stresses; decreased health and vitality of forest ecosystems due to the cumulative impacts of multiple stressors; deteriorating health of forest-dependent peoples.

Soils and water: changes in the seasonality and intensity of precipitation, altering the flow regimes of streams; changes in the salinity of coastal forest ecosystems; increased probability of severe droughts; increased terrain instability and soil erosion due to increased precipitation and melting of permafrost; more/earlier snow melt resulting in changes in the timing of peak flow and volume in streams.

Carbon cycles: alteration of forest sinks and increased CO_2 emissions from forested ecosystems due to changes in forest growth and productivity.

Tangible benefits of forests for people: changes in tree cover; changes in socio-economic resilience; changes in availability of specific forest products (timber, non-timber wood products and fuelwood, wild foods, medicines, and other non-wood forest products).

Intangible services provided by forests: changes in the incidence of conflicts between humans and wildlife; changes in the livelihoods of forest-dependent peoples (also a tangible benefit); changes in socio-economic resilience; changes in the cultural, religious and spiritual values associated with particular forests.

From the above, it is evident that one particular impact could be affecting a number of the thematic areas – changes in the magnitude and frequency of forest disturbances will affect all the ecosystem services provided by forests. Consequently, many adaptation options focus on reducing the potential impact of major disturbances. It is important to emphasize here that we specify no direction in the potential changes. For example, in some areas, the magnitude and/or frequency of disturbances may actually decrease. However, under all climate scenario clusters (see Chapter 3), the magnitude and frequency of forest disturbances are predicted to increase in one or more parts of the world.

Numerous possibilities exist to meet the challenges presented above. In forest management, these include both reducing the effects of potential impacts and developing new management practices and strategies to take advantage of new opportunities under a changing climate. These adjustments will also involve taking into account the perceptions of climate risk by the various stakeholders or 'actors' of change (individuals, communities, governments, private institutions and organizations) (Adger et al. 2007). The adjustments will be influenced by the adaptive capacity of the forest ecosystem, and by the socio-economic communities and the political setting of the forest. An example, drawn from the tropical rainforests of Latin America, is provided in Box 6.1.

6.2 Adaptation and Adaptive Management

Many of the actions that a manager might take to help forests and forest-dependent communities adapt to climate change involve substantial amounts of uncertainty. Adaptive management provides a mechanism to move forward when faced with such uncertainty. In general, adaptive management can be viewed as a systematic process for continually improving management policies and practices by monitoring and then learning from the outcomes of operational programmes. Within the context of climate change, forest management aims at moderating or offsetting the potential damage or taking advantages of opportunities created by a given climate change. In this context, adaptive forest management is one tool that could enable managers to adjust the structure and the consequent functioning of the forest ecosystem to resist harmful impacts of climate change, and to utilize the opportunities created by climate change.

Adaptive management involves a process of observation, analysis, planning, action, monitoring, reflection and new action (Figure 6.1). A key part of the process is to ensure that there is adequate monitoring of the effectiveness of management actions: are they

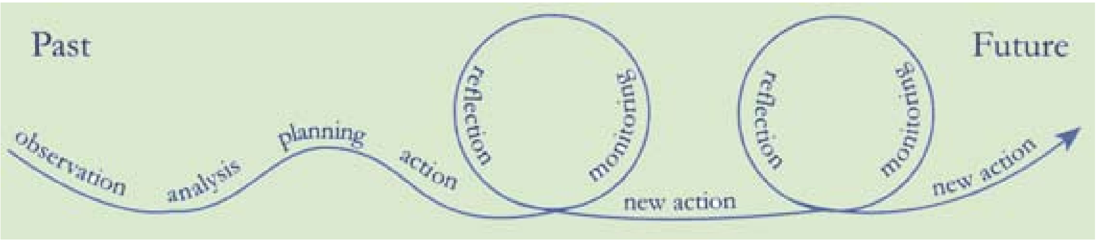

Figure 6.1 Framework for Adaptive Management (Colfer 2005a).

Box 6.1 Community forest management as an option for adaptation of forest-dependent people in the tropical rainforests of Latin America

The natural forests of the tropics store as much carbon in vegetation and soil as the temperate and boreal forests combined (Field et al. 1998, Fischlin et al. 2007). However, in the tropical forests, sustainable forest management is the exception rather than rule (e.g. FAO 2007). Millions of hectares of tropical rain forest disappear every year (FAO 2007), and an unknown, possibly even greater area of forests is degraded in different degrees by unplanned timber and non-timber harvesting activities. A number of options aimed at reducing the risk of forest loss are proposed in Appendix 6.1. Governments have implemented many of them in one way or another in the recent past without much success; deforestation continues. This does not make the presented options less valid. Rather, in order to be more successful in the future, it is necessary to analyse why in some cases the proposed actions have been implemented with more success than in others.

Between 2005 and 2007, about 20 forest-related scientists working in Latin America did such an analysis about community forest management (CFM), one of the options also proposed in Appendix 6.1: 'Enhance local welfare through the promotion of community-based forest management and restoration, the development of agroforestry, the availability of microfinance, training in non-wood forest product (NWFP) management, manufacturing and marketing, and a greater role for women.' The scientists concluded that after twenty years of support to community forest management, and over 200 million hectares of forest land conceded to indigenous people in Latin America (Sunderlin et al. 2008), a number of promising examples exist (Sabogal et al. 2008). From the literature search and their own experiences in CFM, they considered that some of the main factors that contributed to the success of these examples were:

- CFM differs according to the natural and cultural settings of each community and therefore may require local solutions. Institutional support should allow for such adaptations rather than focus on the requirements of CFM under 'average' conditions.
- Development of an integrated approach towards CFM, combining local knowledge with science-based knowledge and allowing the communities to develop according to their own priorities. This may require supporting agencies to adapt their own objectives, working methods and time-spans to those of the local communities.
- Many techniques and methods used to promote CFM have been designed for industrial settings (e.g. forest inventories, mechanized harvesting). Communities that were able to adapt these to their own needs (e.g. multi-product forest inventories) and capacities have been more successful in the continued implementation of CFM.
- Different approaches to entrepreneurial community level organizations (community companies, alliances, productive arms of political organizations) have helped the insertion of communities into market economies. These need to be analysed on a case-by-case basis.
- Local people were able to strengthen their skills and become more involved in CFM where community forest organizations have been able to build on the existing skills and regulations that govern social relations and natural resource use.
- Existing external institutions (political framework, markets) that facilitate the insertion of small producers and indigenous people (e.g. Fair Trade labels) may need to be adjusted (Sabogal et al. 2008).

These experiences suggest that for many Latin-American forests the successful application of the adaptation options proposed in this report will also require an analysis of the best way to apply them. Although many suggestions call for small adjustments in existing SFM practices, an in-depth analysis of SFM and the needs and skills of its different potential practitioners is needed to extend the forest area under SFM, in particular in forest areas assigned to (indigenous) communities.

achieving the desired results and have there been any unintended or underestimated consequences?

The terms adaptation and adaptive management are often incorrectly used interchangeably. The former involves making adjustments in response to or in anticipation of climate change and there are a wide variety of adaptation options that a forest manager may consider (see Appendices 6.1 to 6.9) whereas the latter describes a management system that may be considered, in itself, to be an adaptation tactic

(Ogden and Innes 2007). True adaptive management rigorously combines management, research, monitoring and the means of changing practices so that credible information is gained and management activities can be modified by experience; it is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programmes (BCMOF 2006a). Its most effective form – 'active' adaptive management – employs management programmes that are designed experimentally to compare selected policies or practices, by evaluating alternative hypotheses about the system being managed (BCMOF 2006a). Adaptive management involves recognizing uncertainty and establishing methodologies to test hypotheses concerning those uncertainties; it uses management as a tool not only to change the system but to learn about the system (Holling 1978, Lee 1993, 2001).

The concept of adaptive management has, for many ecologists, become a foundation of effective environmental management for initiatives characterized by high levels of ecological uncertainty (Gregory et al. 2006). However, many of the initiatives promoted as examples of adaptive management appear to lack essential characteristics of the approach. Gregory et al. (2006) proposed explicit criteria to assist forest managers to determine the appropriateness of either passive or active adaptive-management strategies as a response to dealing with uncertainty in decision-making. They suggest four criteria – dealing with spatial and temporal scale, dimensions of uncertainty, the evaluation of costs and benefits, and institutional and stakeholder support – and apply these criteria to four case-studies with different management contexts and with an expressed desire to adhere to adaptive management principles. In doing so, they showed that adaptive management may be more appropriately applied in some contexts than in others.

This reflects the realization that adaptive management goes beyond the focus on scientific method, statistical design and analytical rigour favoured by its early proponents (e.g. Walters 1986). Instead, there is now an expectation of much greater stakeholder involvement in adaptive management, such that the entire concept has been renamed adaptive collaborative management (Colfer 2005b, Diaw and Kusumanto 2005) or adaptive co-management (Armitage et al. 2007). To be effective, there will need to be much greater cooperation between stakeholders, more flexibility for management actions, a social license for action in the absence of conclusive evidence or understanding, and effective ways for including what scientific expertise there is in political and social processes that inform, educate and modify policy (Stankey 2009).

Climate change poses other challenges to the effective application of active adaptive management experiments. The long time frames required to gather information from experiments may not match the time frames required for decision-making, and may exceed the professional lifetimes of several generations of managers. In addition, when results do become available from lengthy experiments on topics such as tree species establishment, growth and survival, they may no longer be relevant as the climate continues to change. It is important to recognize that many of the issues facing adaptive management may have less to do with the approach itself than with the indiscriminate choice of contexts within which it is now applied (Gregory et al. 2006). Applying adaptive management principles as an approach to SFM is not simple. It requires effort at many levels and ongoing commitment in order to be effective.

While the adaptive-management cycle has been widely cited in forestry as a means to deal with the uncertain outcomes arising from management actions, it is important to recognize that there are other knowledge systems (e.g. local knowledge) and that these could also be used to deal with the uncertainties associated with climate change. Managers often discount such alternative management systems, mainly because they have been trained in 'scientific' approaches to forest management. However, the alternative management systems are increasingly recognized as being important and containing invaluable local information relevant to management.

The need for adaptation within forest management varies across ecosystems and tenure types and is related to the vulnerability of forests to climate change as well as to the vulnerability of forest-dependent people to changes in the provision of ecosystem goods and services. The United Nations Development Programme – Global Environment Facility has developed an Adaptation Policy Framework (APF) that provides an approach that permits users to clarify their own priority issues and to implement adaptation strategies, policies and measures (Lim and Spanger-Siegfried 2005).

The APF has four basic principles. Lim and Spanger-Siegfried (2005) list these as:

- Adaptation to short-term climate variability and extreme events is included as a basis for reducing vulnerability to longer-term climate change.
- Adaptation policy and measures are assessed in the context of development.
- Adaptation occurs at different levels in society, including the local level.
- Both the strategy and the process by which adaptation is implemented are equally important.

A key feature of the APF is flexibility, and this is directly applicable to the adaptation of forest management in response to climate change. There is no 'one size fits all' solution, and there is also recognition that the sustainable management of ecosystems is not only extremely complex (Harris 2007), but that ecosystems that we classify as similar (e.g. tropical forests) in reality may respond very differently to external stresses (cf. Savory and Butterfield 1999). Managers must be given the flexibility to respond in ways that meet their particular needs, and only those options that are applicable to the local situation should be adopted (Lim and Spanger-Siegfried 2005). For example, a manager working with tropical forest plantations may only need to consider an 8–20-year time-span (the length of a rotation), while a manager dealing with semi-natural forest in the boreal domain may have to consider a 120-year time-span.

Managers adopting the APF can follow a clear pathway that involves several steps. These are (Lim and Spanger-Siegfried 2005):

1. scoping and designing the management
2. assessing current vulnerability
3. assessing future climate risks
4. formulating an adaptation strategy
5. continuing the adaptation process.

The pathway assumes a linear development, and may be disrupted by the impacts of extreme events. An important aspect of this approach is the final step. Both the climate and forest ecosystems are constantly changing, and managers will need to adapt their strategies as the climate evolves over the long term. An option that might be appropriate today given expected changes over the next 20 years may no longer be appropriate in 20 years' time. This will require a continuous programme of actions, monitoring and evaluation – the adaptive management approach described above.

6.3 Management Options for Maintaining and Providing Forest Ecosystem Services

6.3.1 Introduction

A key argument made in this report is that forest management actions taken to adapt to climate change can be consistent with actions taken to manage forests in a more sustainable fashion. This argument has been made on a number of occasions (e.g. ITTO 2008), and has recently been put forward in relation to climate change mitigation (Putz et al. 2008b). The potential for a win-win situation exists for forest stakeholders: whichever scenario of climate change turns out to be closest to reality, actions will have been taken that will be of long-term benefit to the forest. Similarly, many management actions taken in the context of adaptation, such as the establishment of shade trees in urban areas or the prevention of large-scale forest fires, could also assist in the mitigation of climate change (Ravindranath 2007). To be effective in mitigation, forests will have to adapt to climate change. Ensuring that they are will bring benefits not only to the forests and to climate-mitigation efforts, but will have additional benefits associated with poverty reduction and the preservation of ecosystem services (Eliasch 2008).

Throughout this report, a number of trends are apparent. Firstly, as described in Chapter 3, there are many possible ways that the climate could develop: the likely climatic futures suggested by the IPCC are based on the analysis of many possible scenarios of human development over the next 100 years. In addition, the General Circulation Models currently used to examine the possible future climate associated with any given scenario differ in their outputs, particularly as the scale is decreased (from continental to regional to local)(Chapter 3). Secondly, there are many possible impacts of climate change on forests, but these will differ according to location, past history, vegetation type, management activities and a range of other factors.

A forest manager considering taking action to promote the adaptation of a forest to climate change is faced with a range of choices. Some of the potential actions may actually counteract one another – balancing the consequences of management actions is a critical part of modern forest management (Buongiorno and Gilless 2003, Kangas et al. 2008, Bettinger et al. 2009). Many actions that a manager is likely to take will be based on past experience. There is often a basic assumption that any changes caused by climate will be similar in impact to those caused by other factors, but this is unlikely to be true. Climate change may result in the development of new forest ecosystems not previously encountered, will change site/species relationships, will alter the relative growth rates of different species and provenances within species and will cause a range of other changes. In addition, human activities may mitigate or accelerate the effects of climate change (cf. Laurance and Peres 2006), and the forest manager needs to be able to recognize these interactions and, through negotiation with other stakeholders, prevent their negative impacts and promote their positive effects. Human-induced fires, for example, contribute to the vicious circle of forest degradation, climate warming, drier areas and increased fire hazard (Nepstad 2007, Betts et al. 2008a, Aragão et al. 2008).

Sub-chapters 6.3 to 6.6 of this report are based on the assumption that appropriate management can be used to sustain forest ecosystem services. This is not necessarily happening: the International Tropical Timber Organization (ITTO 2006) reports that only

4.5% of the 814 million ha of natural forest in the permanent forest estate of its producer member countries is managed truly sustainably, although there are plans in countries such as Brazil (e.g. Verissimo et al. 2002, Schulze et al. 2008) to increase the area of forest managed using sustainability criteria. Elsewhere, while there are many claims that forests are being managed sustainably, the majority of management units fulfil only a proportion of the requirements of true sustainable forest management. This is partly because it is possible to cover all the requirements of sustainable forest management at the scale of a large forest or region, whereas many management units are smaller than this, and most management is still focused at the scale of the tree and stand. This situation suggests that adaptation options depending upon additional forest management will be increasingly difficult to implement unless the social factors that influence current management (or lack of management) are addressed.

Over the past 20 years, the forest sector has reached broad agreement on the criteria that determine sustainable forest management. Forests are now considered to be social-ecological systems that involve both nature and society. The management of the societal impacts of altered forests and the actions of society on altered forests are just as important as the management of the biological systems, without taking into account societal linkages. Sustainable forest management is today as much about the people who inhabit, work in or utilize forests as it is about the forest ecosystems themselves, and this changed emphasis is likely to continue into the future. Such changes have been expressed in the four types of services described in the Millennium Ecosystem Assessment (MEA) and introduced in Chapter 1 and expanded upon in Chapter 3, namely supporting, provisioning, regulating and cultural services.

In the following sections, management responses to potential impacts of climate change on the ecosystem services provided by forests are examined. The MEA services classification has been further divided into the thematic elements of sustainable forest management, based on those agreed by the United Nations Forum on Forests (UNFF 2004), since these may be more familiar to many forest managers. Each section is linked to a table providing examples of potential adaptation options. The tables, provided in the Appendices, are not intended to be prescriptive. Rather they present a series of possibilities that managers might like to consider. It will not be possible to utilize every option at every site, as the choice of option will depend on the management objectives of the forest, the nature of the forest and the likely change in climate. Some of the options are incompatible with others, and managers will need to adopt some of the more sophisticated planning techniques and decision analysis tools that are available today to work out which options will generate the desired outcomes. A description of these tools is outside the scope of this report. In addition, managers need to decide how proactive they wish to be: are they trying to facilitate ecosystem adaptation or engineer resistance through proactive management strategies (Joyce et al. 2008)? As indicated in the following chapter, forest policies need to allow sufficient flexibility to enable managers to utilize the range of options that are available to them (Bodin and Wiman 2007).

Planning for sustainable forest management occurs at three levels: strategic, tactical and operational (Bettinger et al. 2009). Strategic plans provide direction on how the mix of forest resources will be managed in a given area and are concerned with larger areas and longer time frames. They often describe desired future forest conditions and indicate broad strategies for how these conditions will be achieved, such as landscape zoning. Tactical plans are shorter term than strategic plans, and focus on how a strategic plan will be implemented. Operational plans are developed to be consistent with the objectives established in the strategic plans and are developed for smaller areas and shorter time frames (often less than a year). They provide detailed descriptions how activities will be undertaken. In practice, one or more of the planning levels may be merged with another in order to save time and costs. Consistency between the different levels of planning has been found in practice to be essential; strategic plans play an important role in determining the appropriate choice of forestry practices described in operational plans, and tactical plans describe how the objectives identified in strategic plans are to be implemented. Because of the differences in strategic, tactical and operational planning, it is important to distinguish at which planning level adaptation options are most appropriately considered (Ogden and Innes 2007a). In the long term, and in the light of eventual climate impacts, the implementation of climate-change adaptation options in both strategic and operational plans will be necessary to realize sustainable forest management. In the tables presented in the appendices, potential management actions have been divided into strategic and operational actions, reflecting whether an action lies closer to either end of the management spectrum.

An important element of any adaptation strategy will be to ensure that adequate monitoring is undertaken. The monitoring needs to be capable of documenting changes in forest species, processes and ecosystems, and should also be capable of enabling the evaluation of the effectiveness of adaptation strategies. This is a critical part of the adaptive management described in the previous section. To date, the forest community has been slow to establish monitoring schemes to achieve these aims, relying instead on adapting existing monitoring. While this may be appropriate for some situations, an important point is that new indicators and sampling designs will be required to monitor the impacts of climate change on forests properly.

6.3.2 Forest Management Strategies to Maintain the Extent of Forests

This is the first of the thematic areas of SFM developed by the United Nations Forum for Forests (UNFF 2004). Essentially, there is a desire to ensure that the global area of forests is maintained. This reflects the global concerns about the current loss of forests, particularly in tropical and subtropical regions (FAO 2007), and the impacts of these losses on global climate (Houghton 2003, Hassan et al. 2005, Fischlin et al. 2007). Such concerns have prompted calls to help mitigate the effects of climate change by reducing emissions of greenhouse gases from deforestation and forest degradation (e.g. Stern 2006, Eliasch 2008). It is difficult to say how forest area will be affected by climate change: for example, there is much speculation about the rate of pole-ward expansion of forests associated with climate change. While the distributions of many temperate and boreal tree species appear to be controlled primarily by energy constraints associated with different life-history strategies (Morin and Chuine 2006), the range of factors affecting forest dynamics in the arctic make such predictions very difficult (cf. Gamache and Payette 2005). Similarly, the future dynamics of the grassland–woodland ecotone in subtropical and tropical regions remains difficult to predict because of the many different factors that influence it (see Box 6.2). The number of tree species in tropical forests makes predictions of the responses of closed tropical forests to climate change difficult, especially given the challenges facing the collection of information on the ecophysiology of tropical tree species (cf. Mulkey et al. 1996, Turner 2001, Chambers and Silver 2004, 2005).

At a regional scale, it is unlikely that the present extent of current forests types will be maintained. In some places forest area will decrease as the environmental conditions become unsuitable for trees. In areas where moisture availability becomes a controlling factor, closed forest will change to open forest and savannah. In other areas, forest area will expand, either as a direct result of climate change (e.g. at the current northern and southern limits of forests) or as a result of afforestation policies (e.g. China, Cuba, Iceland, Vietnam). Within this context, the use of plantation species better adapted to future climate conditions than existing native species is an adaptation option. However, in addition to forest area, the many other factors that modern forest management involves need to be taken into account. For example, replacement of non-forest vegetation types with exotic plantations can be controversial (e.g. Myklestad and Saetersdal 2005, Buscardo et al. 2008), although impacts can mitigated (cf. Candan et al. 2006) and plantation forests can provide more habitat for native species than grazing land (Brockerhoff et al. 2008b). Alteration of groundwater levels caused by new plantations is also a controversial issue (Scott 2005, van Dijk and Keenan 2007; see also sub-chapter 6.5.1).

The cumulative impact of deforestation and forest degradation on the global extent of forests is a major concern, but primarily an issue associated with the mitigation of climate change. It is here that appropriate policies will have the greatest impacts on the processes affecting climate change. To a certain extent, this is addressed elsewhere in this chapter under the themes of biological diversity, water resources, multiple socio-economic benefits and contributions to global carbon cycles. However, there are possible options specifically aimed at maintaining forest cover: examples are detailed in Appendix 6.1.

With the global demand for wood continuing to increase, and the area of natural forest available for harvesting continuing to decline, increasing emphasis is being placed on high-yield plantations. In 2000, 35% of the global roundwood supply and 8% of fuelwood was derived from plantation forests (Sampson et al. 2005). In New Zealand, wood from plantations has entirely replaced the logging of natural forests and although vigorously resisted, a similar trend is occurring in Australia. Such plantations usually have much lower levels of genetic, species and ecosystem diversity than natural forests (Barlow et al. 2007a, 2007b), but may still have some value for biodiversity (Brockerhoff et al. 2008). The use of plantations to supply an increasing amount of wood or other products can reduce the continued long-term loss of biodiversity by avoiding deforestation and forest degradation in other areas, provided that the establishment of plantations is not preceded by the clearing of natural forests.

Attempts are being made in some parts of the world (especially central and northern Europe and western North America) to convert plantations to more natural forms of forest. While this may be at the cost of timber productivity, other ecosystem services provided by forests may benefit. An alternative strategy is to develop zones across the forest management unit, with areas reserved for conservation, areas with extensive forestry (which to a certain extent attempts to mimic natural forest ecosystems) and areas with intensive production where the primary focus is on timber productivity (Nitschke and Innes 2005, 2008). Such an approach is frequently referred to as TRIAD management (Hunter 1990, Thompson and Welsh 1993, Hunter and Calhoun 1996). Climate change

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Photo 6.1 Dead white spruce (*Picea glaucens*), Kluane, Yukon Territory, Canada. The spruce have been killed by the Spruce Beetle (*Dendroctonus rufipennis*), a species that is normally limited by cold winter temperatures. A series of warmer-than-average winters have allowed populations to develop, resulting in the mortality of almost 400 000 ha of this boreal forest.

is likely to influence the nature and success of such conversions since current planning is based on a status quo, instead of considering forest development under climate change.

The current emphasis on alternative fuels such as bioethanol is generating pressure for the creation of biomass plantations in areas currently without forest or with degraded, secondary or even primary forest and for the conversion of some forests managed for multiple purposes to forests managed for biomass production. There are many potential implications of this, ranging from loss of biodiversity (e.g. Robertson and van Schaik 2001, Aratrakorn et al. 2006, Chey VunKhen 2006, Peh et al. 2006,) to impacts on local communities (e.g. Sandker et al. 2007). Conversion of primary forest to oil palm plantations may actually result in net carbon emissions (Reijnders and Huijbregts 2008). However, there are also examples of positive impacts associated with such plantations, and any development needs to be considered within its relevant context.

6.3.3 Forest Management Strategies to Facilitate Natural Adaptation of Biological Diversity

Forest biodiversity is essential to support the ecosystem services provided by forests and to maintain the adaptive capacity of forests to climate change (Noss 2001, Drever et al. 2006). Forest managers have various tools and options to manage forests for a continuous supply of these services, at various scales from large regional scales to forests stands. The effects of climate change will alter forests in many ways, will change the local biodiversity and will result in a change in many of the services available from forests in given areas (Hannah et al. 2002, Malhi and Phillips 2005, IPCC 2007, Millar et al. 2007). Effects will include altered forest ecosystems (species composition and structure), altered processes (increased fire, increased insect attack, extreme events leading to gaps, and altered productivity) and altered physical habitats (changes in forest microclimates) (McCarthy 2001, Parmesan and Yohe 2003, Lewis et al. 2004, 2006, Pounds et al. 2006, Millar et al. 2007, Joyce et al. 2008). Some of these changes may result in the extinction of species, particularly in some specific areas, such as mountains in tropical areas (e.g. Williams et al. 2003, Pounds and Puschendorf 2004, Andreone et al. 2005, Pounds et al. 2006, Rohan et al. 2007, Laurance 2008). Forest managers can adapt to many of these changes by changing their management regimes and activities; at a minimum, they can 'hedge their bets' with respect to climate change and, at best, respond to climate change by managing forests at multiple scales to reduce the long-term effects of climate change on the services that they expect from their forests (e.g. Millar et al. 2007). Work should be directed towards determining the best actions for resisting change, enabling systems to respond to and recover from change, and facilitating the inevitable changes in forest systems (Millar et al. 2007). The avoidance of undesirable impacts on biodiversity is a key aspect of sustainable forest management (see, for example, Hawksworth and Bull (2006). Conversely, many forestry activities are specifically intended to maintain or increase biodiversity (e.g. Hunter 1999, Lindenmayer and Franklin 2002, Newton 2007). A number of options are listed in Appendix 6.2.

A range of management actions may be taken to assist biodiversity adaptation to climate change (e.g. Hannah et al. 2002, Biringer et al. 2005, Lamb et al. 2005, Carnus et al. 2006, Brockerhoff et al. 2008, Killeen and Solórsano 2008). Such activities represent a major potential role for forest managers in the future. In taking any action, forest managers need to consider what the forest composition might be under different scenarios of climate change, since major changes are likely in some areas (e.g. Betts et al. 2008b, Iverson et al. 2008, Phillips et al. 2008). Any management action should be designed to increase the forest's ability to achieve this new composition through an understanding of natural processes (Hannah et al. 2002). This is particularly important given that under some scenarios of climate change some species may be unable to adapt sufficiently quickly without assistance (e.g. Savolainen et al. 2007, Aitken et al. 2008), with closed forests in some areas being replaced by woodland, scrub or grassland (e.g. Barlow and Peres 2008, Betts et al. 2008b).

Over broad regions, forest management could employ landscape-level strategies to conserve biodiversity (Brockerhoff et al. 2008) by enabling natural migration of species to areas with more suitable climates, the so-called 'new climate space' (Pearson et al. 2002). Such strategies would include reducing fragmentation and maintaining connectedness, especially between various protected areas. This is a complex issue, as not only are geographic corridors necessary, but it is also important to ensure that corridors providing different stages of forest development are present. This is because some species need particular stages of forest development for their survival, as has been shown for saproxylic insect assemblages in boreal forests (e.g. Cobb et al. 2007, Jacobs et al. 2007, Spence et al. 2008).

Managers might reduce anticipated effects of increased fire on biodiversity by developing species mixes across landscapes that reduce the spread of fires (Hirsch 2001) and by enhancing fire-fighting capacity. At a stand level, managers could protect isolated populations of species at the northern edges of their ranges and enhance their capacity for successful reproduction. Assisted migration of provenances and species might be used to enable forest types to adapt to climate changes (Millar et al. 2007). The goal of such strategies would be to reduce the effects of climate change on the services provided by forests.

In some cases, conditions may become unsuitable for forests at a given location. The relationship between grassland, woodland and closed forest may change, with the future vegetation type being determined by the particularities of the climate and soil and by management activities such as fire and grazing (Dubbin et al. 2006, Umbanhowar et al. 2006, Rull 2007). There is experience in the ecology and management of such ecosystems (and changes between them), particularly in Australia (McIntyre et al. 2002, Lindenmayer et al. 2005, Banfai et al. 2007, Kirkpatrick and Bridle 2007), but also in the savanna landscapes of other subtropical and temperate domains (e.g. Augustine et al. 2003, Savadogo et al. 2007, Oluwole et al. 2008, Scott et al. 2008). One of the biggest difficulties for forest managers will be associated with changes in land use as the vegetation changes. For example, as the canopy opens or fires become more frequent, grass species can increase in abundance, making the land attractive for livestock grazing, with subsequent implications for tree regeneration (e.g. Prober et al. 2007, Spooner and Biggs 2008).

Over the long term, managers will also have to recognize that an altered set of services may be produced and adapt management programmes accordingly. Similarly, in areas where there is a high probability that forests will be lost in favour of other ecosystems, such as grasslands, managers should recognize early on that their efforts and resources may best be focused elsewhere. The strategies employed will depend on the expected rate and scale of change, the capacity of the managers to initiate measures, the political will to act on recommendations for adaptation and the ability to shift the geographic location of the economic activities, although in many situations, such a shift may be impossible. Capacity is particularly important, as many small-scale landholders will have insufficient capacity to initiate the types of changes that may be necessary (Brondizio and Moran 2008, Guariguata et al. 2008).

The actual rate of change in forested ecosystems, and the rate of change in the distribution of individual species, is uncertain (Malcolm et al. 2002) but forests are long-lived and may show gradual responses (Millar et al. 2007). Projections for the spread of species with climate change are based on estimates derived from the early Holocene period, when a period of warming following the last glacial period was accompanied by the pole-ward spread of many species (e.g. Malcolm et al. 2002), or, as in the Amazon region, replacement of biomes in some ecotonal areas (Mayle and Power 2008). However, conditions today are very different largely owing to past human activities and it is uncertain whether the use of historic rates is appropriate (e.g. IPCC 2007). In practice, knowledge of the dispersal abilities of most tree species is very poor, particularly the conditions determining long-distance dispersal (Clark 1998, Clark et al. 1998, 1999, Kutter and Gratzer 2006). It may be necessary to assist certain species to move in response to changing conditions, for example, by moving seeds to more suitable locations or by even storing seeds ex situ until conditions stabilize.

The maintenance or creation of corridors may be an important strategy to help the movement of forest-dependent species to areas with more suitable climate conditions (Williams et al. 2005, Chapin et al. 2007, Mayle et al. 2007). However, this is likely to be particularly important for populations that are already small and isolated, such as the giant panda in the subtropical forests of south-west China (Yin et al. 2006). Several different types of corridor may need to be envisaged, including those that connect habitats at different heights above sea level and those that help maintain current biological diversity by providing functional connectivity between forest patches. However, evidence supporting the effectiveness of such corridors is limited (e.g. Beier and Noss 1998), and the speed of the current change in climate may be too great for the distribution of species to adjust, either with or without such corridors.

An important strategy in any long-term management plan to adapt to climate change is to include the use of reserves in enabling systems to adapt naturally to climate change in the absence of active management, and in increasing landscape connectivity (Noss 2001, Vos et al. 2008). Because of the uncertainty of its long-term effects, climate change presents some significant challenges for the location and design of forest reserves. Nevertheless, there has been too little recognition of the extent of this issue (Scott and Lemieux 2007), leading to protected area policies and a distribution of protected areas that are unrelated to projected climate change. In other areas conservation strategy recommendations may give much consideration to future climate change projections based on one or a few models (e.g. Killeen and Solórzano 2008) without considering information on adaptations in response to past climate changes (e.g. Mayle and Power 2008) or the impact projections of other models.

A common theme in this report is the high level of uncertainty about the precise long-term effects of climate change (Kirilenko and Sedjo 2007). However, in the long term, forests will benefit from adaptation actions at multiple scales to conserve biological diversity, even if the ecosystems that develop differ markedly from current forests (e.g. Hannah et al. 2002). It is important to recognize that climate change has strong potential to affect biodiversity negatively. Adaptation should thus aim at taking appropriate actions to attempt to conserve, as well as possible, existing forest biodiversity in areas with suitable conditions and at managing change as efficiently as possible to improve future forest conditions (Noss 2001, Millar et al. 2007).

6.3.4 Forest Management Strategies to Maintain Forest Health

There is considerable evidence that climate change will affect the health and vitality of forests. These effects may be subtle and long term, such as the spread of some pathogens, medium-term events such as droughts and insect epidemics, or they may be sudden and catastrophic, such as the occurrence of extreme storms and fires. Forest management can aim to reduce the impact of such events, but the events themselves may provide the opportunity for adaptation by removing the inertia within a forest that buffers it against change. Similarly, disturbances may enable shrubs and trees to colonize habitats from which they were previously excluded; such change has been suggested for the tundra (Landhäusser and Wein, 1993, Johnstone and Chapin 2006). The microclimate within a forest is very different from that outside the forest, with temperature variations and air movement being lower and atmospheric humidity generally higher. If the forest canopy is removed, this microclimate is lost, and the success of any regeneration will be determined by the atmospheric conditions. Under such circumstances, managers must make the decision whether to try to reduce any major changes in the forest (thereby making it more susceptible to future events), or allow the events to occur (thereby perhaps losing some of the goods and services provided by the existing forest). At the same time, managers must consider the wide range of potential consequences that may be associated with salvage operations (Lindenmayer et al. 2008). Potential strategies are listed in Appendix 6.3.

If the forest canopy is lost, then a manager is faced with important decisions. Current forestry practice for natural forests suggests that attempts should be made to replace the forest with the same species composition as the original forest. However, this fails to take into account that the existing forest

Box 6.2 Fire and drought in southern Africa

Fire regimes of southern Africa are much more under climatic control than human control, as was previously believed (Geldenhuys1994). Therefore it is reasonable to assume that the future fire regime will change, especially in response to the amount and seasonal distribution of rainfall. Contrary to patterns observed in boreal and temperate forests, both the frequency and intensity of fires in southern African subtropical forests *decrease* as the rainfall decreases, because less grass fuel is available to support the fire (Scholes 2004). Furthermore, the fraction of the landscape burned tends to decrease with increasing human population density. A reduction in fire frequency and intensity, all else being equal, is expected to shift the tree-grass balance towards trees (Bond et al. 2003).

Rising temperatures and increasingly variability of rainfall will generally affect surface waters, increasing drought in some regions and causing floods in others. There is likely to be a general decrease of 5–10% of present rainfall, with longer dry spells in the interior and north-western areas coupled with more frequent and severe droughts (Christensen et al. 2007). The fraction of rainfall that becomes runoff is a strong function of rainfall amount, especially in the rainfall range from 500 to 1200 mm. At 500 mm the fraction is about 5%, whereas at 1200 mm it can approach 40%. Below about 500 mm, the rivers are ephemeral, and local people (and some ecosystems) depend on groundwater. Recharge, as a fraction of rainfall, is very small – in the order of 1% – and highly sensitive to changes in net wetness and storm intensity. The projection (low certainty) is for a decrease in groundwater recharge in the dry south-west of southern Africa as soon as 2015 and is expected to reach the east coast by 2060 (De Wit and Stankiewicz 2006). Current policies are encouraging removal of alien vegetation, which has resulted in a major rise in water table in a 30-year period and control of water use. No development decision should be made without taking into account the actual or potential effects of climate change on water resources.

was probably established under different climatic conditions from those at the site today, and that there is a strong possibility that whatever caused the canopy loss will occur again under future climates. There is a widespread assumption that the forest currently at a site is adapted to the current conditions, but this ignores the extent to which the climate has changed over the past 200–300 years, and the lag effects that occur in forests. As a result, replacement of a forest by one of the same composition may no longer be a suitable strategy.

Forest fires are likely to be increasingly important in many parts of the world as climate changes. In many cases, fire hazard may increase, but this may not be universal (see Box 6.2). Forest fires associated with extreme droughts are projected to increase in neotropical forests (e.g. Cox et al. 2004, Nepstad et al. 2004, Scholze et al. 2006), and drought-associated fires have already been noted in the Amazon (Brown et al. 2006, Aragão et al. 2008). Guariguata et al. (2008) argue that this threat can be reduced through the implementation of reduced impact logging (see Putz et al. 2008a), but also point out that like other disturbances, fire hazard is affected by a number of factors, some unrelated to climate change. For example, fires in Brazilian Amazonia can be directly related to frontier advance, and preventing indiscriminate frontier advance will be an important strategy to reduce the impacts of such fires (Laurance and Fearnside 2002, Laurance 2004, Barlow and Peres 2005). However, climate change may increase the susceptibility of the forest to fire, just as it has enabled the spread of bark beetles in the example described in Box 6.3. The impacts will vary from forest to forest, even in an area such as the Amazon Basin, depending on the range of factors that affect the occurrence of forest fires (e.g. Ray et al. 2005, Balch et al. 2008). The co-occurrence of increased fires and increased drought frequency may be particularly important for tropical forests because of their effects on smaller and larger trees, respectively (van Nieuwstadt and Sheil 2005).

The interaction between fire, timber production and other forms of land use is important. Adaptation to a future increase in fire frequency is likely to take a number of forms, depending on the local situation. In some cases, it may involve educating local communities about the risks associated with fires, and encouraging the communities to become involved with fire management. In others, physical precautions, such as the establishment of unvegetated buffer strips between plantations and the surrounding vegetation, may be necessary, although the effectiveness of these needs to be tested. Such strips are already standard practice around blue-gum plantations in southern Australia (Photo 6.2).

In most forest types, the magnitude and frequency of disturbances are likely to increase. This will result


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Photo 6.2 Fire damage to a blue-gum (*Eucalyptus globulus*) plantation on Kangaroo Island, South Australia (Jarmyn Plantation, planted 2005). This plantation abuts the Flinders Chase National Park, much of which was burnt in December 2008 following a prolonged drought. The plantation was separated from the park by a highway, a roadside strip of remnant native vegetation and a buffer strip (clearly seen in the photo). The fires jumped the highway, burning the roadside vegetation, but did not take hold in the plantation, only scorching marginal trees. Buffer strips such as these may have to be used much more frequently in many areas if plantation investments are to be protected.

in an increase in tree mortality. Dealing with this mortality will be a major issue for many managers. The traditional response to such disturbances has been to salvage the timber, sometimes in ways and at rates that would not be acceptable under normal conditions. For example, the Yukon Government in Canada has issued requests for tenders to salvage one million m^3 of white spruce killed by the spruce bark beetle (*Dendroctonus rufipennis*) in an area that previously had no significant forestry activities. In Victoria, Australia, changes were made to state-authorized harvesting levels to allow for an increase in salvage following extensive mortality caused by fires in 2002–2003 and 2006–2007 (Victoria Government Gazette 2007). The issues surrounding salvage logging are unlikely to be resolved in the near future, but steps taken to decrease the susceptibility of forests to large-scale disturbances will also decrease the likelihood of large-scale salvage operations. A full discussion of salvage logging and its implications is provided by Lindenmayer et al. (2008).

The likelihood of devastating attacks by pathogens will probably vary by domain. For example, some temperate forests, most boreal forests and many plantation forests throughout the world are monospecific or comprise a limited number of species. Such forests are more likely to be impacted by a pathogen benefiting from changed climate conditions. Because of the host-specificity of most pathogens, major outbreaks affecting most or all trees are anticipated to occur more in low-diversity forests than in high-diversity forests, and therefore unlikely in the species-rich forests of the subtropical and tropical domains. However, plantation forests in the tropics may be susceptible to major pathogen attacks, as illustrated by the mortality caused by *Sphaeropsis sapinea* of large areas of Caribbean pine (*Pinus caribaea* var. *hondurensis*) in Venezuela following an El Niño event (Cedeño et al. 2001).

Box 6.3 Mountain pine beetle in British Columbia, Canada

In British Columbia (BC), a total of about 13.5 million ha of lodgepole pine (*Pinus contorta*) has been killed by the Mountain Pine Beetle (*Dendroctonus ponderosae*). The extent of the mortality has been caused by a combination of large amounts of susceptible lodgepole pine in the landscape, exacerbated by reforestation and fire-suppression policies, and warmer winters, which have reduced the winter mortality of the beetles. After several years of tracking the progress of the infestation, the Government of British Columbia responded by raising the annual allowable cut to facilitate large-scale industrial salvage operations. The magnitude of the infestation, along with the Provincial objective to recover as much economic value as possible from the infestation while respecting the other services provided by the forests, necessitated the implementation of measures to help communities deal with economic and social impacts (BCMOF 2006b). Unprecedented levels of financial resources were allocated to combating the infestation, strengthening the long-term competitiveness of the forest industry and facilitating worker adjustment, among other initiatives. The very large volumes of timber that became available coincided with a major downturn in new housing starts in the USA (the major market for BC lumber) and near parity of the Canadian and US dollars, which made Canadian lumber more expensive in the USA. In addition, the recent softwood settlement between Canada and the USA capped the amount of lumber that Canada can export to the USA without triggering significant tariffs.

In 2006, a major flight of the Mountain Pine Beetle (MPB) crossed the Rocky Mountains into Alberta. Almost immediately, Government of Alberta spending on forest health skyrocketed. The objective of the Alberta programme is to contain infestations and prevent the spread northward and eastward into the boreal forest (ASRD 2007a). Short-term management responses are guided by an assessment of the current status and risk of spread. Three MPB management priority zones are designated annually – Leading-Edge, Holding and Salvage – which determine levels of management and control strategies (ASRD 2007b). An elaborate decision support system was constructed to aid in the timely identification of Level 1 (individual tree treatment) and Level 2 (block or patch harvesting of infested areas) treatment priorities within these zones. The current level of funding supports Level 1 treatment of 120 000 to 180 000 locations per year. Longer-term management responses are guided by the objective to reduce the amount of susceptible pine by 75% over the next 20 years. This is primarily concerned with altering age structure rather than species composition (which must remain the same at the landscape level). At the time this report was completed, more effort is being directed to Level 1 search-and-destroy tactics than to Level 2 tactics to reduce amount of vulnerable stands. The Government of Alberta also took steps to clarify the roles and responsibilities of different organizations on different land tenures to manage the infestation, in part a response to the softwood lumber agreement (ASRD 2007c).

The different nature of the management response to the MPB infestation in BC and Alberta deserves mention. In Alberta, mobilizing management response to the infestation occurred much more quickly than in BC. Alberta witnessed BC's experience and therefore was able to envisage what the scale of the infestation might become in planning their initial response whereas BC had no precedent to work from. Both jurisdictions have multiple objectives in responding to the infestation that include dealing with the short-term consequences of the epidemic and managing for multiple values, but BC's response is more focused on recovering economic value and Alberta's is more focused on stopping the spread of the MPB and associated damaging impacts on forests. On-the-ground salvage in BC is largely being carried out by industry, whereas in Alberta the Alberta Government is making a tremendous effort to contain the infestation at the scale of individual trees. Under BC's forest legislation, the licensees have an obligation to re-forest any cut areas. In most cases, lodgepole pine is being used to reforest the salvage sites, a practice that will result in large areas of even-aged lodgepole pine forest and encourage the re-creation of the same conditions that allowed the current epidemic to occur. Given that current climatic predictions are for progressively warmer winters, it seems likely that the forests being replanted today will be vulnerable to future outbreaks. Alberta on the other hand has adopted a very explicit policy to reduce vulnerable stands across the landscape by altering age structure and therefore has more explicitly incorporated future climate change considerations into its management response than BC.

Which of these two approaches will ultimately have more success in achieving sustainable forest management objectives? This may only be known with time. To aid in any future retrospective assessments, a typology for classifying sustainable forest management plans according to how they address climate change has been suggested. It consists of a matrix that categorizes plans into one of four types: (1) proactive-direct, (2) proactive-indirect, (3) reactive-direct, and (4) reactive-indirect (Ogden and Innes 2008a). This typology recognizes that adaptation to climate change can be carried out in response to, or in anticipation of, the changes and may either directly or indirectly acknowledge climate change as a driver of change. According to this typology, the BC response may be characterized as reactive-indirect and the Alberta response as both proactive-direct and reactive-indirect. To date, there is little research available on the cost-benefits of these differing approaches and how successful these approaches will be in addressing and managing the risks posed by climate change.

6.4 Management Options for Maintaining and Providing Provisioning Services

6.4.1 Forest Management Strategies to Maintain the Productivity of Forest Ecosystems under Climate Change

Changes in the productivity of forests associated with climate change will very much depend on the local situation. In some cases, productivity is likely to increase (e.g. Ollinger et al. 2008), whereas in others, there will be a loss in productivity (Clark et al. 2005, Feeley et al. 2007). There is already evidence of increased biomass in some tropical forests (e.g. Baker et al. 2005, Phillips et al. 2008), and increased growth has also been reported in temperate and boreal forests (e.g. Spiecker 1999). Another possibility is that productivity may increase and then fall as the growth response saturates (Phillips et al. 2008). A meta-analysis of tree productivity responses (Boisvenue and Running 2006) has suggested that where water is not limiting, productivity will generally increase. This is, however, very complex, and a range of different factors are involved in determining the final productivity of forests. Some of these are independent of climate change, such as nitrogen deposition, whereas others are directly related (e.g. increasing concentrations of atmospheric carbon dioxide – Laurance et al. [2005] or increased solar radiation as a result of reduced cloudiness – Lewis et al. [2004]) or indirectly related (e.g. increased nutrient deposition from increasing forest fires – Artaxo et al. [2003]).

While most studies to date have concentrated on the potential impacts of climate change on the production of fibre resources, increasingly there are concerns about the productivity of non-timber products such as medicines and foods. Relatively little information is available in the scientific literature about the sustainable management of such products (but see Peters 1994 and Shanley et al. 2002), and even less is known about their vulnerability to climate change.

Box 6.4 presents the results of a study on the effects of selected management regimes on the growth of different tree species in a Scandinavian boreal forest. Potential responses (see Appendix 6.4) will be the cumulative result of a number of different factors. These include water availability, response to elevated carbon-dioxide levels, changes in vegetation patterns, changes in pathogen distributions and

Box 6.4 Productivity and the current patterns of timber production – an example on management to adapt forests to the climate change in the boreal conditions (Kellomäki et al. 2007)

As the simulation example for the boreal forests in Chapter 3 showed, the productivity of forest ecosystems may be reduced, because climate change may create a suboptimal environment for Norway spruce, especially in southern parts of Finland (6062 ºN). Obviously, there are two main tasks in adapting to the climate change: i.e. to maintain (i) the productivity of the forest ecosystems and especially (ii) the growth of Norway spruce if the current patterns of timber production are preferred in the future. In the following simulation example, several strategies were applied in reformulating the current management to meet the changes in the climate.

First, the length of the rotation was reduced by making the terminal cut (clear cut) earlier than in conventional timber production but still aiming at producing saw timber and pulpwood. *Second*, Norway spruce was replaced by Scots pine or birch on sites of medium fertility, and Norway spruce was preferred only on sites with high fertility, if it had occupied the site prior to the terminal cut. *Third*, a more southern provenance of Norway spruce was used in planting. Regarding Norway spruce, the new provenance was described by changing the maximum and minimum temperature sum in the temperature sum multiplier of the growth model. Now, the maximum values were 2500 d.d. (previously 2060 d.d.) and the minimum value 360 d.d. (previously 170 d.d). The outlines of the model and the input representing the climate and the initialization of the simulations are given the Chapter 3.

Table 6.1 shows that the reduction of rotation length reduced the mean growth of Norway spruce (up to 16%) but increased the total growth representing all tree species (up to 28%), because the growth of Scots pine and birch increased. The increase was the largest in the south, where the total mean growth increased up to 35%. This was much more than that obtained when preferring Scots pine on sites of medium fertility (12%); i.e. the increased growth of Scots pine did not compensate the reduction in the growth of Norway spruce and birch. On the contrary, when birch was preferred the total growth increased most (38%). The use of the more southern ecotype of Norway spruce also

Box 6.4. continued

Table 6.1 Mean growth of different tree species in southern and northern Finland (2070–2099) under selected management regimes (Kellomäki et al. 2007). South refers the forests below 62°N and north to the forests above 62°N. *Myrtillus* **site type refers to the sites of medium fertility.**

Management strategy	Mean growth, m^3 ha^{-1} yr^{-1} (% of that under the current management rules)			
	Scots pine	Norway spruce	Birch	Total
Strategy 1: Management with no modifications of the current management rules.				
South	2.81	0.26	3.62	6.69
North	3.19	0.58	0.84	4.61
Total	2.96	0.39	2.49	5.84
Strategy 2: Management with terminal cut, when the minimum diameter requirement is exceeded.				
South	3.42 (+22)	0.24 (–8)	5.36 (+48)	9.02 (+35)
North	3.70 (+16)	0.49 (–16)	1.07 (+27)	5.26 (+14)
Total	3.54 (+20)	0.34 (–13)	3.62 (+45)	7.50 (+28)
Strategy 3: Preferring Scots pine if the site previously occupied by Norway spruce. Terminal cut at the minimum diameter requirement.				
South	4.06 (+44)	0.17 (–35)	3.29 (–9)	7.53 (+13)
North	3.99 (+25)	0.39 (–33)	0.70 (–17)	5.08 (+10)
Total	4.03 (+36)	0.26 (–33)	2.24 (–10)	6.53 (+12)
Strategy 4: Preferring birch on *Myrtillus* site if previously occupied by Norway spruce. Terminal cut at the minimum diameter requirement.				
South	3.12 (+11)	0.17 (–35)	6.79 (+88)	10.08 (+51)
North	3.53 (+11)	0.49 (–16)	1.14 (+36)	5.16 (+12)
Total	3.29 (+11)	0.30 (–23)	4.49 (+80)	8.08 (+38)
Strategy 5: Preferring Norway spruce of more southern ecotype. Terminal cut at the minimum diameter requirement.				
South	3.04 (+8)	0.67 (+158)	5.56 (+54)	9.27 (+39)
North	3.60 (+13)	0.44 (–24)	1.23 (+46)	5.27 (+14)
Total	3.27 (+10)	0.57 (+46)	3.80 (+53)	7.64 (+31)

increased the total growth (31%). It seems that a proper choice of tree species and provenance are the basis for an adaptive management when aiming at maintaining the productivity of forest land under the climate change. Furthermore, reduced rotation length with more rapid turnover of forest resources may help to maintain the productivity and makes it possible to modify the management strategies to meet changes in site conditions under the changes in climate.

a range of other factors, making predictions very difficult (Kirilenko and Sedjo 2007). The modelling studies that have been undertaken to date are highly dependent on the factors included in the models, and different approaches can generate divergent results (for example, an increase versus a decrease in productivity – cf. Girardin et al. 2008). It is also apparent that local factors play a major role in determining the productivity responses (e.g. Loustau et al. 2005, Su et al. 2007), making broader extrapolations difficult. This means that models must be carefully calibrated using local, empirical information and that the results of any models should only be extrapolated beyond the area for which they were derived with great care (Nigh 2006). In addition, growth models are often based on biophysical processes and do not account sufficiently for social considerations. Despite these constraints, it is evident that improved silviculture could increase the productivity of both temperate and boreal forests (Nabuurs et al. 2008) and tropical forests (Peña-Claros et al. 2008).

Many productivity issues are now being addressed through genetics. Genetic studies are likely to shed some light on the extent to which forest trees will be able to adapt to climate change. Projects such as EVOLTREE (Kremer and Six 2008) are aimed at identifying the genes that control the adaptive ability of trees and examining their frequency amongst forest trees. With the recent publication of the draft sequence of the poplar (*Populus trichocarpa* Torr. & Gray ex Brayshaw) genome (Tuskan et al. 2006), and the much larger *Pinus* genome expected soon,

Box 6.5 The use of genetically modified organisms

While not discussed in the definition of sustainable forest management provided in Chapter 1, there are some groups with their own definition of SFM, such as the Forest Stewardship Council, that consider the use of genetically modified trees to be irreconcilable with the principles of SFM. The use of genetically modified trees has been listed as one possible adaptation option – whether or not it is adopted by a particular manager will depend on a range of factors, including whether or not the use of such trees is legal within a country and whether or not the public will accept them. There are strong arguments both for and against such use, and the reader is referred to Strauss and Bradshaw (2004) for a discussion of the subject.

there will be a better understanding of the genomic attributes that affect the phenotypic performances of trees growing in different environments (Nelson and Johnson 2008). For a short note on genetically modified organisms see Box 6.5.

There are concerns that the productivity of plantations in temperate and boreal regions may be adversely affected by climate change, with many such plantations potentially suffering from dieback due to drought and other stresses (Sohngen et al. 2001). As a result, there may be greater global demand for forest products from tropical and subtropical forest plantations (Guariguata et al. 2008). The ability of such plantations to meet this demand will depend on how well adapted they are to the evolving climate. Tropical plantations are more likely to remain viable under future climate than temperate and boreal plantations, as the shorter rotation times will reduce the risk of maladaptation and damage by extreme events during a particular rotation. Plantation species such as *Casuarina equisetifolia* (used in India), *Eucalyptus grandis* (used in Brazil), *Gmelina arborea* (used in Malawi and west Africa) and *Leucaena leucocephala* (used in the Philippines) are all fast-growing and reach maximum growth rates relatively early (Evans and Turnbull 2004).

The principles of sustainable forest management mean that the rate of timber removal should be appropriate for the forest while maintaining all other ecosystem services. In the past, this has been interpreted as ensuring that a sustained yield of timber is maintained. However, today, it is more determined by the range of services provided by forests and the values that a manager is seeking to maintain. Despite this, many jurisdictions still attempt to determine an annual allowable cut. However, very few, if any, cut determinations factor in predicted changes in productivity associated with climate change. This is an important omission that needs to be rectified.

6.4.2 Forest Management Strategies to Maintain the Tangible Socio-Economic Benefits from Forests under Climate Change

While changes are likely to occur in the distribution and composition of forests, the impact of these changes on the production of tangible socio-economic benefits from forests will be strongly influenced by the markets for those socio-economic benefits and other potential uses of forest land. For example, while some ecological models have suggested that declines in productivity or large-scale losses associated with drought and fire may occur (e.g. Botta and Foley 2002, Oyama and Nobre 2003, Cox et al. 2004), economic models of the forest sector have suggested that when producers implement adaptation options in forest management for timber and wood products, globally the impact on the forest sector is small (Irland et al. 2001, Sohngen et al. 2001, Joyce 2007). These studies suggest that though there may be some local negative impacts, the impacts are more likely to be positive for a larger share of the population. Market forces can shift the supply between regions in the world, between landowners within a region, and between softwood and hardwood harvests (Kirilenko and Sedjo 2007). When climate change causes large-scale, widespread dieback, timber prices will be depressed due to anticipatory harvest and salvage.

The potential decrease in the economic resilience of forest-dependent communities is a trend of particular concern. This has already been seen in some communities, as in central British Columbia where forests have been devastated by the mountain pine beetle (Parkins and MacKendrick 2007). However, any community currently dependent on forestry is at risk of destabilization, some more seriously than others. There is likely to be a high level of variation in the ability of forest-dependent communities to adapt to climate change (see Chapter 4), but there have been relatively few rigorous studies investigating this. One study in northern Europe revealed that

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Photo 6.3 Clearance of montane tropical rainforest for agricultural gardens at Poring, Sabah, Malaysia. Any steps to manage tropical forests more sustainably must take into account the complex relationships between the welfare of local people and global concerns such as climate change. The social factors that force people to burn forest need to be examined carefully and addressed. The adverse impacts of climate change may actually result in some forest-dependent people relying even more on forest resources, leading eventually to over-exploitation and forest degradation and loss.

the communities in Norrbotten (Sweden), Lappi (Finland) and Arkhangelsk oblast (Russia) differed markedly, primarily because of their varying degrees of dependence on natural resources and their ability to counteract negative effects (Lundmark et al. 2008).

The top-down imposition of adaptation strategies could lead to conflict amongst different stakeholder groups (Deshingkar 1998). There is therefore a need for the careful evaluation of local preferences (Keskitalo 2008, Ogden and Innes 2008b) and implementation of the preferred adaptation options. In some cases, local communities may lack understanding of the nature or extent of the problems faced (cf. Guariguata et al. 2008), or may have difficulty perceiving climate change as a risk (e.g. Davidson et al. 2003). In such cases, the problems may well become manifest as a result of disturbances. Fires, pathogen outbreaks or forest dieback may result in major short-term changes in the services provided by forests, causing immediate impacts on the livelihoods and welfare of local people. Adaptive approaches will require the sharing of knowledge and the integration of informal networks, yet this may be difficult to achieve (see for example, a discussion of the problems facing such an approach in Canada by Wellstead and Stedman, 2007).

In tropical areas, trees planted by smallholders may play an important part in the landscape, providing a range of goods and services. Such trees may be impacted by climate change, and adaptation mechanisms are required (Guariguata et al. 2008). Smallholders may need external assistance in implementing adaptations but, at the same time, participatory approaches to adaptation, such as participatory tree improvement (Simons and Leakey 2004) may offer considerable potential.

While relatively few studies exist, it can be expected that communities that depend on a single or very few forest products will be more vulnerable to climate change (or any other external shock) than communities that use a whole range of products, several of which may have different responses to climate change (Parkins and MacKendrick 2007). As pointed out by Thomas and Twyman (2006), the greater the diversification of a local economy, the less its vulnerability to climate change is likely to be because of its ‘room for maneuver’. Potential strategies to maintain the tangible socio-economic benefits are listed in Appendix 6.5.

6.5 Management Options for Maintaining and Providing Regulating Services

6.5.1 Forest Management Strategies to Maintain Soil and Water Resources under Climate Change

Climate change may have major impacts on the environment, through droughts, floods, increased erosion, landslides, melting of permafrost and other impacts. Some of these phenomena, such as droughts, soil erosion and landslides, are natural processes that can be affected by human activities. Consequently, the forestry community has long recognized that protection forests are an important means to safeguard infrastructure and human life, and are widely used in mountain areas. However, existing strategies towards the maintenance of protection forests may have to be changed in the light of climate change, and new strategies to cope with some of the other changes that climate change will induce may have to be developed. The potential management strategies to maintain soil and water resources under climate change are listed in Appendix 6.6.

Protection forests can be natural forests (Sakals et al. 2006, Wilford et al. 2006) or planted forests (Evans and Turnbull 2004). They are also increasingly being used to stabilize sand dunes and desert margins in areas affected by desertification. For example, in China, the Three North Shelterbelt Development Programme and the Shelterbelt Development Programme along the Yangtze River Basin has been designed to alleviate desertification in the Three North Region. If successful, the current phase of the programs will afforest 9.46 million hectares of land and bring 1.3 million ha of desertified land under control between 2001 and 2010. By the programmes' end, forest cover in the programme areas will have been increased by 1.84%, 11.33 million ha of farmland will have been put under shelter, and 12.66 million hectares of desertified, salinized and degraded grasslands will have been protected and rehabilitated. In the lower-middle reaches of the Yangtze River the programme will afforest 18 million ha of land, improve 7.33 million ha of low-efficiency shelterbelts and regulate and protect 37.33 million ha of existing forests (Wang et al. 2008). To enable them to fulfil their expected functions under future climates, it will be necessary to manage protection forests actively. If they are left unmanaged, the evidence that we have suggests strongly that they risk being degraded and losing their protective abilities.

In many countries, forested catchments provide an important source of drinking water. Water demand is expected to grow globally, but current water-management practices are very likely to be inadequate to cope with the effects of climate change (Kundzewicz et al. 2007). The capacity of the forest ecosystem to purify water is an important service, obviating the cost of expensive filtration plants. Consequently, management operations need to be undertaken with care. For example, it may be necessary to leave a buffer strip of forest between a stream or river and any area used for forestry operations (e.g. Laurén et al. 2005).

There may, however, be negative effects for soils and water associated with forests and their management. In particular, forest roads are an important source of erosion (Grace and Clinton 2007), and major adaptations to their design and use will have to be made to avoid increased erosion associated with the more intense rainfall events that are expected in many areas (e.g. Bruijnzeel 2004). The interaction between stormflow events and soil changes associated with harvesting activities will require particular attention (cf. Waterloo et al. 2007). While the effects of roads are clear, the impact of afforestation on processes such as infiltration are currently unclear (e.g. Ilstedt et al. 2007) and therefore difficult to predict under future climates.

Forests use more water than grasslands, and in areas where water supply is an issue, afforestation projects may result in lowered water tables and reduced stream flows (e.g. Buytaert et al. 2007, Dye and Versfeld 2007, Trabucco et al. 2008). This is a complex subject with little agreement amongst hydrologists and foresters on many of the relationships between forest cover and water supply under different conditions (Vertessy et al. 2003, Calder 2005, Jackson et al. 2005, Nambiar and Ferguson 2005, Chang 2006, van Dijk and Keenan 2007).

Generally, current efforts to maintain the quality and quantity of soils and water associated with forests may have to be intensified. Most current efforts focus on minimizing damage through prescriptive or legislative approaches, and there is a lack of monitoring to determine the effectiveness of such approaches.

6.5.2 Forest Management Strategies to Maintain and Enhance Forestry's Contribution to Global Carbon Cycles under Conditions of Climate Change

The importance of forests in global carbon budgets was emphasized by the United Nations Framework Convention on Climate Change in December 2007. The Bali Action Plan built on the IPCC's Fourth Assessment Report that found that forestry (including deforestation) contributes 17% of the total annual carbon emissions (Rogner et al. 2007), and defores-

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Photo 6.4 Protection forest consisting of Atlas Cedar (*Cedrus atlantica*) in the High Atlas Mountains, Morocco. Such forests play an important role in stabilizing steep slopes and protecting people and infrastructure from natural hazards such as rockfall and landslides. However, there is evidence that climate change may be destabilizing this species (Chenchouni et al. 2008), and management practices, such as the choice of species in afforestation programmes, may have to be adjusted.

tation alone contributes 5.8 GTCO$_2$/yr (Nabuurs et al. 2007). Particular emphasis is now being placed on reducing emissions from deforestation and forest degradation (REDD). Forests represent an important means of mitigating climate change (Canadell and Rapuach 2008), but they will be effective in doing so only if the forests can adapt to the changes in climate that will occur in the future. The total potential of forests to reduce atmospheric carbon is limited given current atmospheric releases, although in some tropical countries emissions from deforestation may be greater than other forms of GHG emissions. However, reducing emissions from forests and using forests for carbon sequestration can both help to reduce the current rate of increase in atmospheric CO$_2$ while other options are being pursued (especially a reduction in the release of CO$_2$ from the burning of fossil fuels). In addition, reducing deforestation and forest degradation will have a number of other benefits, including the protection of biodiversity (O'Connor 2008) and promoting the relief of poverty (Singh 2008).

Mitigation and adaptation are not readily separated when considering carbon sequestration. Many adaptation strategies also need to take into account the potential mitigation, especially as mitigation represents an ecosystem service for which there is potential for payment (Canadell and Rapuach 2008). Mitigation may therefore represent a potential means by which adaptation measures could be financed (Osafo 2005, Santilli et al. 2005, Silva-Chavez 2005, Nepstad et al. 2007, Canadell and Raupach 2008, Bellassen and Gitz 2008, Putz et al. 2008b), and such measures are therefore included in this report (Appendix 6.7).

Large-scale afforestation has been suggested as a means to increase the sequestration of atmospheric CO$_2$ by forests, even though such projects are unlikely to have a major impact on global carbon sequestration (Strengers et al. 2008). Such recommendations often come from groups with strong vested interests, including the forestry and biofuel lobbies. However, it is important to note that afforestation and reforestation also reduce albedo, particularly in high-latitude regions, and thereby can contribute to atmospheric warming. As a result, the benefits associated with afforestation and reforestation may be least in the boreal domain, and feedback loops should be carefully considered when developing strategies to increase carbon sequestration (Bala et al. 2007, Chapin et al. 2008). Such results, combined with the adaptation benefits associated with short rotations associated with tropical plantations, strongly suggest that afforestation efforts should be focused in tropical and subtropical regions. However, the impact on local livelihoods of land-use conversion needs to be considered when assessing the potential costs and benefits of afforestation projects aimed at carbon sequestration (Leach and Leach 2004, van Noordwijk et al. 2008, Zorner et al. 2008).

The carbon balance of some areas could be adversely affected by climate change, and forest carbon management could play an important part in mitigating any adverse effects. For example, climate models show strong agreement that the peatland forests of South-east Asia will experience increasing dryness, making them more susceptible to drying out and to fire (Li et al. 2007). Wildfires and insect outbreaks have changed the forests of Canada from being a CO_2 sink to being a CO_2 source (Kurz et al. 2008a, 2008b). Such changes may require drastic management actions, particularly in honouring a country's Kyoto commitments.

6.5.3 Forest Management Strategies to Regulate Human Diseases

Under criteria and indicator schemes adopted as part of sustainable forest management, forest health and vitality is usually taken to refer to the health and vitality of trees, particularly those of commercial value. However, the concept should be extended to the entire forest ecosystem and, in addition, should cover the health of forest workers and other forest-dependent people, as they are a part of the forest ecosystem. This approach is consistent with the rapidly increasing evidence for the close connections between human health and forests (e.g. Colfer et al. 2006, Colfer 2008a, 2008b) and the recognition that these connections could be affected by climate change (Menne et al. 2002). For example, there is considerable evidence that bat-borne viral zoonoses may be impacted by climate change, and it has been hypothesized that the SARS coronavirus, Ebola fever and Nipah encephalitis are all in some way related to direct or indirect changes in the relationships between people and forest-dwelling bats (Gonzalez et al. 2008).

The strategies listed in Appendix 6.8 indicate that a range of activities are necessary. Many of these relate specifically to tropical and subtropical forests, but it is important to remember that there are also important interactions between forests and human health in the temperate and boreal zones. In particular, forests within and close to urban areas are likely to play an increasingly important role under future climates. There is already evidence that forests can alleviate the effects of extreme temperatures, as shown during the 2003 heatwave in Europe (Renaud and Rebetez in press). As the amount of recreational time available to people increases, there is likely to be increased demand for recreation in forests, as well as the possibility of using them for therapeutic purposes. Visits to forests can increase the human natural killer cell activity (Li et al. 2008a, 2008b), reduce stress (Yamaguchi et al. 2006, Morita et al. 2007), reduce blood glucose levels (Ohtsuka et al. 1998) and generally improve mental and physical health (Ohira et al. 1999). As a result, in countries such as Japan and South Korea, there is a strong interest in health-related recreational activities in forests.

6.6 Management Options for Maintaining and Providing Cultural Services

6.6.1 Cultural Values and Local Knowledge

Forest cultural values are generally deeply ingrained (cf. Harrison 1992, Nakashima 1998, Hayman 2003). Climate change may alter some of the cultural attributes of forests. The prediction of such changes and the development of adaptation strategies for them are difficult. For example, the ability of some indigenous groups to hunt, trap and fish in forests represents an important survival process for some groups. However, such actions may also have strong cultural significance (e.g. Flood and McAvoy 2007, Griffin 2007, Levang et al. 2007) and may be central to maintaining some traditional aspects of the cultures of forest-dependent people, such as language. This is not restricted to indigenous groups. In the temperate and boreal zones, hunting remains a strong institutional and cultural tradition for many people, and its loss may be vigorously resisted (as demonstrated in the United Kingdom when the government banned fox-hunting). In relation to climate change, institutions will have to be sufficiently flexible to ensure that it is possible to maintain cultural traditions as the forests change. In the case of hunting, new potential quarry species may replace traditional ones, and changes to legislation may be required to ensure that these can be legally hunted.

Many traditional practices are not always easily 'translated' into the language of modern forest science (Berkes et al. 2000, Kimmins 2008). However, they have enabled traditional societies to cope with environmental change in the past (e.g. King et al. 2008b) and could provide these communities, and society in general, with adaptive management approaches and specific forest-management techniques for dealing with increased climate variability, changes in the frequency and intensity of natural

Photo 6.5 Sacred forest grove near Lhunze in Tibet, China. The intangible benefits associated with such forests are impossible to quantify, and it is very uncertain how climate change will affect them.

forest disturbances (such as storms, fire, drought, alien invasive species), alterations in forest structure and composition, and other expected impacts of climate change (Scotti and Cadoni 2007). Such adaptations may, however, be compromised by other, non-climatic changes, such economic and legal constraints on traditional activities (e.g. Xu et al. 2005, Tyler et al. 2007). Potential adaptation strategies to provide and maintain cultural services are listed in Appendix 6.9.

6.6.2 Forest Management Strategies to Maintain the Aesthetic Services Provided by Forests

It is also extremely difficult to determine how adaptation might maintain the aesthetic values associated forests, as there are major cultural differences in how forest aesthetics are considered. For example, major disturbances such as storms and fires are likely to reduce the aesthetic value of forests (e.g. Hunt and Haider 2004), but the mortality of individual trees may create opportunities for more biodiversity, increasing the aesthetic and recreational (such as for bird-watching) opportunities of the forest. Relatively little work has been done in this area, although there are a few studies (e.g. Galečic et al. 2007), and it is likely that more research will be conducted as the occurrence of disturbances to forests used for recreation and for visual quality increases.

6.6.3 Forest Management Strategies to Maintain the Spiritual Services Provided by Forests

Spiritual values are often assumed to be related purely to indigenous groups, because such groups are often recognized as having very strong spiritual links to the land. This is illustrated by the Aboriginal concept of country, expressed by Rose (1996) as: ‘Country in Aboriginal English is not only a common noun but also a proper noun. People talk about country in the same way that they would talk about a person: they speak to country, sing to country, visit country, worry about country, feel sorry for country, and long for country. People say that country knows, hears, smells, takes notice, takes care, is sorry or happy. Country is not a generalised or undifferentiated type of place, such as one might indicate with terms like like “spending a day in the country” or “going up the country”. Rather, country is a living entity with a yesterday, today and tomorrow, with a consciousness, and a will toward life. Because of this richness, country is home, and peace; nourishment for body, mind, and spirit; heart’s ease.’ However, spiritual and cultural links extend far beyond indigenous groups to all communities (Varner 2006). The knowledge that accompanies such links may be of vital importance in preserving elements of the landscape in the future (e.g. Gómez et al. 2006, Agnoletti 2007). A distinction needs to be made, however, between spiritual and religious values associated with forests. The former are not necessarily associated with any particular religion, whereas the latter always are. Forests or stands within forests with religious significance are frequently referred to as sacred groves (e.g. Gaisseau 1954, Spindel 1989, Decher 1997, Tiwari et al. 1998).

As in a number of areas associated with the cultural services provided by forests, very little research has been undertaken on the effects that climate change may have on the spiritual services provided by forests. However, any increase in the occurrence of forest disturbances is likely to have impact on the spiritual value of the forests. This is particularly true given that many spiritual values are associated with larger and older trees (Alban and Berwick 2004, Lewis and Sheppard 2005). While there have been some attempts to examine the spiritual and religious values of forests (e.g. Melo Filho et al. 2008), such studies have not yet factored in the potential impacts of climate change.

6.6.4 Forest Management Strategies to Maintain the Educational Services Provided by Forest

In the field of education, there is a tendency for conservative approaches to dominate (Innes 2005). The adaptation of forest management to climate change will require new approaches and new ways of thinking, extending well beyond the linear programming methods used in some forestry textbooks (e.g. Davis et al. 2001). More recent textbooks are beginning to include such approaches (cf. Bettinger 2009). In some areas, the conservative approach to forestry has resulted in significant drops in the numbers of students taking up the subject (Leslie et al. 2006, Nyland 2008). This is likely to be a significant problem in many developed countries in the future. In developing countries, the problem is more one of education capacity, combined with the loss of trained foresters from the profession. For example, in much of Africa, there has been a significant loss of expertise in rural workforces due to mortality induced by HIV/AIDS (Anaeto and Emenyonu 2005). Conversely, forestry has been proposed as an important tool in the fight against the HIV/AIDS pandemic in sub-Saharan Africa (Barany et al. 2001, Topouzis 2007), but its role could be compromised by the failure of forest managers to adapt to climate change.

Where they exist, institutions concerned with the maintenance of management standards, such as professional forestry associations, can be equally conservative. Only a few have mandatory continuing education programmes for their members, and there is therefore a significant problem in keeping members up to date with the latest information about climate change. For example, in a survey of forestry practitioners (which included both professional foresters and others with a professional interest in forestry) in north-west Canada, 44% considered that they had poor knowledge of how to respond to climate change (Ogden and Innes 2007b), and climate-change risks are rarely perceived by foresters and forest managers working in tropical forests (Guariguata et al. 2008). This may be because of a lack of information available to managers at appropriate spatial and temporal scales.

6.6.5 Forest Management Strategies to Maintain the Recreational Services Provided by Forests

A variety of recreational activities occur in forests, and climate change may have an impact on many of these. For example, many people visit forests for bird-watching, but birds are particularly sensitive to climate change, and changes in bird populations have already been observed in high-visit areas such as the northern Appalachians of the USA (King et al. 2008a). The importance of forests for recreation is likely to grow in many areas, and the health risks associated with increased numbers of visitors will require careful monitoring (Buckley et al. 2008). It is not clear how climate change will affect this growing demand for recreation. Urban forests are likely to provide a certain amount of relief from heat stress, but only if they maintain their canopies. Consequently, disturbances, especially storms and fires, are likely to reduce the potential value of forests for recreation. The adaptation strategies of the public may come into conflict with those of forest managers, since forest managers may seek to exclude or at least restrict visitors during periods of particularly high fire hazard. Conflicts such as this will need to be resolved locally on a case-by-case basis, reflecting the unique management needs associated with urban forests (Carreiro et al. 2008).

A particular concern is the role that recreation may play in causing problems in forests. For example, the occurrence of *Phytophthora ramorum* (sudden oak death) is known to be accelerated by the presence of hikers, who spread the disease along trails (Cushman and Meentemeyer 2008). Future recreation management will increasingly need to consider the risks associated with public visits to forests.

6.7 Conclusions

It is possible to draw a number of conclusions from the analysis undertaken for this chapter.

- **Learning from past shortcomings in SFM**
  Many of the management options listed in this chapter are closely related to the practice of sustainable forest management (SFM). However, the global forest sector has been slow to adopt the practices of SFM, particularly in developing countries. Much greater efforts are required nationally and internationally to ensure the more responsible stewardship of the world's forests. These actions need to get out of the 'forest' box, learn from past shortcomings and involve actors from other sectors. Global forests are essential to the mitigation of climate change, and also represent a resource used by billions of people. All actors need to work together more effectively to ensure that forests are better managed in all regions.
- **Sustainable forest management options**
  The diversity of forests throughout the world, the differences in management arrangements, and the uncertainties associated with predicting how climate will evolve at any particular location, all make it impossible to provide prescriptive recommendations for the adaptation of forests to climate change. A large number of different potential strategies exist, applicable at strategic or operational levels. The choice of strategies will depend on local situations, but a key conclusion is that many of the actions associated with sustainable forest management present 'no regrets' decisions for forest managers. The strategies listed in this chapter are all consistent with sustainable forest management, although clearly it would not be possible to implement every strategy on a particular piece of ground. Conversely, implementing only the strategies associated with a particular service may cause an imbalance in the overall management of the forest. Instead there are many effective tools that can be used to ensure that tradeoffs are optimized to particular situations. The uncertainties associated with projections of climate change and associated impacts emphasize the need to identify robust management strategies – those that are likely to achieve the objectives of sustainable forest management and are likely to perform well across a wide range of potential future climate conditions. Robust strategies must also be flexible and responsive to new information and therefore incorporate the principles of adaptive management.
- **Taking advantage of opportunities**
  While climate change will present many difficult challenges for forest managers around the world, there will also be opportunities. In some regions, it will be possible to expand forest cover or increase forest productivity. There should be sufficient flexibility within forestry policies to ensure that these opportunities can be developed, always bearing in mind that land potentially becoming available for forests may also be important for alleviating global, national or regional food supply problems.
- **Management to reduce vulnerability to storms, fires, insect pests and diseases**
  In all scenarios and all domains discussed in this report it is very likely that storms, fires, insect attacks and diseases will occur more frequently and at greater intensity. Prevention will require extensive communication networks and monitoring schemes at regional and national level, as well as specific management practices (e.g. controlled burning, sanitary cuts) at local level. This will require considerable investments in infrastructure (communications, watchtowers, road network), training and equipment.
- **Need for more management**
  For adaptation of forests to climate change, a *laissez-faire* approach to forests management will be inappropriate. Active management will be required if specific management values are to be maintained. This will be particularly true for protection forests. For example, in forested watersheds where no management takes place to minimize potential impacts on water supply, it may be necessary to adopt a more active approach. The need for more management implies additional costs, and it is important, particularly in developing countries, that opportunities to finance these costs through payments for mitigation services are realized. To do this, it is essential for decision-makers to recognize that adaptation and mitigation are closely linked. To date this thinking has not been included in many of the national and international policies developed in relation to climate change, At the same time, it is also important to recognize that failure to adopt management actions now is likely to result in increased costs in the future. Managers need to be pro-active and adopt strategies that may be beyond all past experiences.
- **Adaptive management**
  A key strategy applicable to all forests, regardless of which scenario is used, is adaptive co-management. While much research has been undertaken, there are large gaps in our knowledge of the impacts of climate change and the most appropriate adaptation strategies. For individual managers, the most appropriate management approach in many cases (but not all) given such uncertainty is adaptive co-management. Policies and regulations must be sufficiently flexible to

allow adaptive co-management to take place, and there needs to be a recognition that mistakes will be made. It is important that lessons are taken from such mistakes, and that they are rectified as quickly as possible. Commitments at several different levels are required – not just between scientists and managers but also amongst policy-makers and the public. Effective mechanisms are required to ensure that existing and novel adaptation approaches can be readily 'translated' into policy and practice.

- **Monitoring**
  A key aspect of adaptive co-management is adequate monitoring. This can be undertaken at a range of scales, from the stand to the nation. Stand- and forest-level monitoring are required to determine whether particular management strategies are being effective. National monitoring is required for a number of reasons, such as carbon accounting and as a means of determining how forests and forest communities are adapting to climate change.
- **Integrating ecological, economic and social research**
  Many current forest management practices may be adopted to facilitate adaptation of forests to climate change. However, these practices were developed under climates that may not reflect future novel climates, and proper experimentation to determine the forest response to new and novel management practices under a changing climate will be valuable. Further, the human response to change will be critical in taking advantage of opportunities under the changing climate. Increasing our understanding of what policies and incentives will facilitate human adaptation at the individual, community, company and government level will be important to develop on-the-ground management practices to adapt forests to climate change.
- **Limits to adaptation, limits to mitigation**
  Over the long term, forest managers must make greater efforts than currently both to mitigate and adapt to climate change. Even the most stringent mitigation efforts cannot avoid further impacts of climate change, which makes adaptation essential. However, it is important to understand the limits of adaptation. Unmitigated climate change would, in the long term, be likely to exceed the capacity of natural, managed and human systems to adapt. There is high confidence that the resilience of many ecosystems (their ability to adapt naturally) is likely to be exceeded by 2100 by an unprecedented combination of change in climate, associated disturbances (e.g. flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (e.g. land-use change, pollution, over-exploitation of resources). Adaptation alone is not expected to be able to cope with all of the projected effects of climate change, and especially not over the long run as most impacts increase in magnitude. Adaptations to resource-management policies and practices may only buy ecosystems additional time to adjust to a changing climate until broad global action on reducing greenhouse gas emissions takes effect. In addition, failure to adapt forest-management practices and policies to the realities and uncertainties associated with climate change may impact the ability of forests to mitigate climate change. Therefore, both adaptation and mitigation are essential and complementary approaches to climate change.

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Appendices

Assessment of the likelihood of success of particular adaptation actions in each climatic domain

With each management option, an assessment has been made of the evidence for its likelihood of success in specific regions (B: boreal, Te: Temperate, S: Subtropical and Tr: Tropical). The classification follows the IPCC principles for assessing qualitative information namely, A: much evidence, much agreement; B: little evidence, much agreement; C: much evidence, little agreement; and D: little evidence, little agreement. Care should be taken in interpreting these, as the forests in these broad regions can differ significantly, as can the likelihood of particular impacts. In addition, the available evidence that particular strategies will be successful is very limited, as few properly controlled long-term experiments on the interaction between forests and climate change have been conducted. Instead, these assessments are based on the expert opinion of the authors of the likely impacts of particular management options.

Appendix 6.1 Potential strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining (or increasing) forest area.

Impact	S/O	Adaptation option	B	Te	S	Tr
Conversion of forest to energy plantations	S	Establish policies to limit conversion of existing forest to non-woody energy plantations	C	C	C	C
Deforestation and forest degradation	S	Provide alternative coping mechanisms for vulnerable communities that would otherwise use forests when facing crop and livestock failures	B	B	A	A
		Increase forest law enforcement in areas impacted by illegal logging	B	B	A	A
		Ensure the proper functioning of community governance and equitable sharing of benefits among individual families	B	B	A	A
		Generate means to provide private owners with economic flexibility if they choose to use their land for forestry (similar to the economic flexibility associated with raising livestock)	A	A	A	A
		Enhance local welfare through the promotion of community-based forest management and restoration, the development of agroforestry, the availability of microfinance, training in NWFP management, manufacturing and marketing, and a greater role for women	A	A	A	A
		Improve community and individual welfare through community plantings, village woodlots, shelterbelts, partnerships with private sector and public-awareness campaigns through the media, children's education programmes and field demonstrations	B	B	A	A
		Design and implement REDD mechanisms that allow for a flow of capital to those forest users that decide in favour of sustainable forest use, rather than non-forest use of forest lands	D	D	D	D
		Support efforts to improve welfare through sound governance, strengthening institutions, greater participation and education, greater accountability, reinforced monitoring and community access to benefits	A	A	A	A
Use of wood for domestic energy	O	Substitution of firewood used far from its source by more energy-efficient fuels (e.g. charcoal)	B	B	A	A
		Substitution of firewood and charcoal by renewable energy sources	C	C	B	A

Sources for the adaptation options: FAO 2008.

Appendix 6.2 Potential strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of conserving biological diversity of forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Alteration of plant and animal distribution	S	Minimize fragmentation of habitat and maintain connectivity	D	A	A	A
		Reduce deforested areas to above threshold values (30–40%)	D	A	A	A
		Maintain representative forest types across environmental gradients in reserves	B	B	B	B
		Protect primary forests	A	A	A	A
		Protect climate refugia at multiple scales	B	B	B	B
		Identify and protect functional groups and keystone species	B	B	B	B
		Strategically increase size and number of protected areas, especially in ‘high-value’ areas	B	B	B	B
		Provide buffer zones for adjustment of reserve boundaries	B	A	A	B
		Protect most highly threatened species ex situ	A	A	A	A
		Develop a gene management programme to maintain diverse gene pools	B	B	B	B
		Ensure that conservation corridors extend across environmental gradients	B	B	B	B
		Ensure that infrastructure investments do not interrupt conservation or riparian corridors	D	D	D	D
		Create artificial reserves or arboreta to preserve rare species	B	B	B	B
		Increased regional cooperation in species management and protected areas management	A	A	A	A
	O	Practice low-intensity forestry and prevent conversion to plantations	D	B	A	A
		Assist changes in the distribution of species by introducing them to new areas; establish ‘neo-native forests’	B	B	B	B
		Increase the colonizing capacity in the areas between existing habitat and areas of potential new habitat	A	A	A	A
		Design tree plantations to have a diverse understory	D	D	B	B
		For planted forests, establish indigenous, mixed-species stands, maximize natural genetic diversity, mimic the structural properties of the surrounding forests and avoid direct replacement of native ecosystems	A	A	A	A

Impact	**S/O**	**Adaptation Options**	**B**	**Te**	**S**	**Tr**
Changes in the frequency and severity of forest disturbance	S	Maintain natural fire regimes	A	A	B	B
		Reduce the rate of deforestation and forest degradation	D	A	A	A
		Maintain under and above-ground seed sources (seed banks or trees)	B	B	B	B
	O	Allow forests to regenerate naturally following disturbance; prefer natural regeneration wherever appropriate	D	D	D	D
		Reduce fire hazard by implementing reduced impact logging, especially a reduction in the size of felling gaps and fuel loads	B	B	A	A
Habitat invasions by non- native species or by native species not considered native to this area	O	Control invasive species	A	A	B	B

Sources for the adaptation options: Aragão et al. 2008, Barlow and Peres 2008, Betts et al. 2008a, Biringer et al. 2005, Blate 2005, Carey 2003, Drever et al. 2006, Guariguata et al. 2008, Hannah et al. 2002, Holdsworth and Uhl 1997, Holling 2001, Kellomaki et al. 2005, Killeen and Solórzano 2008, Ledig and Kitzmiller 1992, Loope and Giambelluca 1998, Noss 2001; Parker et al. 2000, Persuy 2006, Peters 1990, Vos et al. 2008.

Appendix 6.3 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining the health and vitality of forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Increased frequency and severity of forest pestilence	S	Adjust harvest schedules to harvest stands most vulnerable to insect outbreaks	B	B	B	D
		Improve governance of frontier forest areas to reduce the risk of fires associated with settlement	D	–	B	B
	O	Plant genotypes tolerant of drought, insects and/or disease	B	A	A	A
		Reduce disease losses through sanitation cuts	A	A	A	A
		Breed for pest resistance and for a wider tolerance to a range of climate stresses and extremes	D	B	B	D
		Used prescribed burning to reduce fire risk and reduce forest vulnerability to insect outbreaks	B	B	B	D
		Employ silvicultural techniques to promote forest productivity and increase stand vigour	C	C	C	B
		Shorten the rotation length to decrease the period of stand vulnerability to damaging insects and diseases and to facilitate change to more suitable species	B	B	B	B
		Increase the genetic diversity of trees used in plantations	B	B	A	A
		Establish landscape-level targets of structural or age-class, of landscape connectivity for species movement, and of passive or active measures to minimize the potential impacts of fire, insects and diseases	B	B	B	B
Increased mortality due to climate stresses	S	Avoid planting new forests in area likely to be subject to natural disturbances (e.g. floods)	C	C	C	C
	O	Minimize amount of edge created by human disturbances	D	D	D	A
		In natural forests, conduct thinning to stimulate crown development and eventual fruiting of seed trees	–	–	B	A
		In natural forests, create canopy or ground disturbances to assist the regeneration of light-demanding species	–	–	A	A
		Maximise number of seed trees retained when harvesting natural forest	–	–	A	A
		For dioecious species in natural forests, retain similar numbers of adult male and female trees to ensure reproduction and maintain genetically effective population sizes	–	–	A	A

Impact	S/O	Adaptation Options	B	Te	S	Tr
Decreased health and vitality of forest ecosystems due to cumulative impacts of multiple stressors	S	Reduce non-climatic stresses, especially air pollution, to enhance ability of ecosystems to respond to climate change	A	A	A	A
		Restore degraded areas to maintain genetic diversity and promote ecosystem health	A	A	A	A
		Conduct monitoring at sub-national and national scales of all forests (not just production forests) through improved national, regional or operational forest health monitoring networks, harmonization of inventory and reporting protocols of such networks and expanding and linking invasive species networks	A	A	A	A
		Pursue better and more cost-efficient methods of multi-scale monitoring systems for early detection of change in forest status and health	A	A	A	A
		Develop, test and improve risk assessment methods	B	B	B	B
		In natural forests, ensure high juvenile population sizes and thus promote high genetic variation	B	B	B	B
		Reduce mortality by reducing the frequency of lianas	–	–	–	A
		Encourage transfer of resources (financial and knowledge) from developed to developing and least-developed countries and build capacity where needed	A	A	A	A

Sources for adaptation options: Ahmed et al. 1999, Battisti et al. 2000, Biringer 2003, Bouget and Duelli 2004, Burdon 2001, Chapin et al. 2007, Coops et al. 2008, Cornelius and Watt 2003, Coyle 2002, Dale et al. 2001, De Dios et al. 2007, De Moraes et al. 2004, Dickmann 2006, Dodds et al. 2007, FAO 2008, Farnum 1992, Foster and Orwig 2006, Fredericksen and Pariona 2002, Friedenberg et al. 2007, Guariguata and Sáenz 2002, Guariguata et al. 2008, Gottschalk 1995, Grogan and Galvão 2006, Grogan et al. 2005, Hurley et al. 2007, Jacobs 2007, Kellomaki et al. 2005, Kizlinski et al. 2002, Koski and Rousi 2005, Laurance 2004, Laurance and Fearnside 2002, Lemmen and Warren 2004, Liebhold et al. 1998, Lindner et al. 2000, Lombardero et al. 2008, Mason and Wickman 1991, Meentemeyer et al. 2008, Moreau et al. 2006, Namkoong 1984, Negron and Popp 2004, Ofori, and Cobbinah 2007, Oliva and Colinas 2007, Opuni-Frimpong et al. 2008, Phillips et al. 2005, Piirto and Valkonen 2005, Schmidt 2003, Schroeder 2007, Sizer and Tanner 1999, Smith et al. 1997, Snook and Negreros-Castillo 2004, Steinbauer et al. 2006, Stone 2001, Turchetti et al. 2008, Tuskan 1998, van Staden et al. 2004, Volney et al. 1999, Wallin et al. 2008, Wang et al. 1995, Wargo and Harrington 1991, Waring and O'hara 2005, Yanchuk et al. 2006, Yanchuk et al. 2008, Yeh 2000, Ylioja et al. 2005, Zanuncio et al. 2001, Zas et al. 2006.

Appendix 6.4 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining the productive capacity of forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in the frequency and severity of forest disturbance	S	Practice high-intensity plantation forestry in areas managed for timber production where an increase in disturbance is anticipated	C	C	C	C
	O	Assist in tree regeneration	B	A	A	A
		Maintain seed banks (in soil or trees)	A	A	A	B
		Actively manage forest pests	A	A	A	A
		Increase the stability of stands through increasing species and structural diversity, de-emphasizing means to enhance or maintain short-term productivity	D	B	D	D
		In drought-prone areas, increase the use of pre-commercial and commercial thinning to enhance the tolerance of the remaining trees and introduce drought-resistant species where appropriate	B	B	B	B
		Preferentially use coastal provenances of species in areas likely to be affected by increased windstorms	–	B	B	B
Changes in forest growth	O	Practice high-intensity forestry in areas managed for timber production to promote growth of commercial tree species	C	B	B	C
		Include climate variables in growth and yield models	A	A	A	A
		Enhance forest growth through forest fertilization	C	C	C	C
		Employ vegetation control techniques to offset drought	C	C	B	B
		Pre-commercial thinning or selective removal of suppressed, damaged or poor quality individuals	B	A	A	A
		Identify more suitable genotypes	A	A	B	B
		Plant genetically modified species	D	D	D	D
		Match provenances to new site conditions	A	A	A	B
		Adjust the annual cut to maintain the forest processes in as close an equilibrium state as possible	A	A	A	B
Increased nitrogen losses	O	Use nitrogen fertilization or encourage N-fixing species in the understory	C	C	C	D

Impact	S/O	Adaptation Options	B	Te	S	Tr
Species are no longer suited to site conditions	O	Underplant with other species or genotypes where the current advanced regeneration is unacceptable as a source for the future forest	D	B	B	B
		Design and establish long-term multi species/seedlot trials to test improved genotypes across a diverse array of climatic and latitudinal environments	A	A	B	B
		Reduce the rotation cycle to speed the establishment of better adapted forest types	C	A	A	D
		Relax any rules governing the movement of seed stocks from one area to another; examine options for modifying seed transfer limits and systems	C	B	A	B
		Use germplasm mixtures with high levels of genetic variation when planting	B	B	B	B
		In plantations, avoid the use of clonal material selected purely on the basis of past growth rates	B	A	B	B
Invasions by non-native species or by native species not considered native to the area	O	Control those undesirable plant species that will become more competitive with harvestable species in a changed climate	B	A	A	B

Sources for adaptation options: Bastien et al. 2000, BCMOF 2006a, Biringer 2003, FAO 2008, Fredericksen and Putz 2003, Garcia-Gonzalo et al. 2007, Guariguata et al. 2008, Gitay et al. 2001, Innes and Nitschke 2005, IPCC 2000, Kellomaki et al. 2005, Kelty 2006, Lamb et al. 2005, Ledig and Kitzmiller 1992, Lemmen and Warren 2004, Lindner et al. 2000, Papadopol 2000, Parker et al. 2000, Peña-Claros et al. 2007, 2008, Petit and Montagnini 2006, Piermont 2007, Sáenz-Romero et al. 2006, Smith et al. 1997, Schulze 2008, Spittlehouse and Stewart 2003, Villegas et al. 2008.

Appendix 6.5 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining and enhancing long-term multiple tangible socioeconomic benefits in forests. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in tree cover	O	Substitution of wood by other fuels for cooking and heating	A	A	A	A
Changes in socioeconomic resilience	S	Anticipate variability and change and conduct vulnerability assessments at a regional scale	A	A	A	B
		Enhance capacity to undertake integrated assessments of system vulnerabilities at various scales	A	A	A	B
		Diversify forest economy (e.g. dead wood product markets, value added products, non-timber forest products)	A	A	A	A
		Diversify regional economy (non-forest based)	A	A	A	B
		Develop technology to use altered wood quality and tree species composition, modify wood processing technology	A	A	B	B
		Make choice about the preferred tree species composition for the future; establish objectives for the future forest under climate change	B	B	B	B
		Increase extension activities in areas subject to high levels of migration and family turnover	A	A	B	B
		Enhance dialogue amongst stakeholder groups to establish priorities for action on climate-change adaptation in the forest sector	A	A	B	B
	O	Conduct assessments in local communities to determine priorities and preferences	B	B	B	B
		Strengthen local organizational and planning skills	B	B	B	B
		Compilation of local and community knowledge about past and current changes	B	B	B	B

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in frequency and severity of forest disturbance	S	Include risk management in management rules and forest plans and develop an enhanced capacity for risk management	A	A	B	B
		Conduct an assessment of greenhouse-gas emissions produced by internal operations	A	A	B	B
		Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions in regard to fuels management and community protection	A	A	B	B
		Encourage appropriate capital investments, re-training of workforce and mobility of the population	A	A	B	B
	O	Protect higher value areas from fire through better fire management planning and precautions ('firesmart' techniques)	A	A	A	B
		Increase amount of timber from salvage logging of fire or insect disturbed stands	A	A	A	B
Changes in demand for nature-based tourism and recreational services	O	Gather information about natural and cultural heritage values and ensure that this knowledge is used as part of the decision-making process established to manage for climate-change impacts.	A	A	B	B
		Establish on-site management programmes designed to plan ecologically, manage carbon sinks, reduce greenhouse-gas emissions, and develop tools and techniques that help mitigate the impacts of rapid climate change	A	A	C	C
		Expand tourism and recreational services to 3 or 4 season operations	A	A	B	–

Sources for adaptation options: BCMOF 2006a, Brondizio and Moran 2008, Chapin et al. 2004, FAO 2008, Johnston et al. 2006, Kellomaki et al. 2005, Keskitalo 2008, Lemmen and Warren 2004, Ogden 2007, Ogden and Innes 2008, Ohlson et al. 2005, Spittlehouse 2005, Spittlehouse and Stewart 2003.

Appendix 6.6 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of conserving and maintaining the soil and water resources in forest ecosystems. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Increased soil erosion	O	Maintain, decommission and rehabilitate roads to minimize sediment runoff due to increased precipitation and melting of permafrost	A	B	A	A
		Minimize soil disturbance through low-impact harvesting activities	A	A	A	A
		Minimize density of permanent road network and decommission and rehabilitate roads to maximize productive forest area	A	A	B	B
		Limit harvesting operations to the appropriate seasons to minimize road construction and soil disturbance	A	A	A	A
		Change road and ski track specifications to anticipate higher frequency of intense rainfall events	B	B	B	A
Increased terrain instability	S	Avoid constructing roads in landslide-prone terrain	A	A	A	A
Changes in the timing of peak flow and volume in streams	O	Examine the suitability of current road construction standards and stream crossings to ensure they adequately mitigate the potential impacts on infrastructure, fish and potable water	A	A	A	A
Changes in the salinity of coastal forest ecosystems	S	Avoid low river flows, especially from up-stream abstraction	B	B	A	A

Sources for adaptation options: BCMOF 2006a, IPCC 2000, Mote et al. 2003, Spittlehouse and Stewart 2003.

Appendix 6.7 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining forest contributions to global carbon cycles. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Alteration of forest sinks and increased CO_2 emissions from forested ecosystems	S	Mitigate climate change through forest carbon management	B	B	B	B
		Increase forested area through afforestation and reforestation of degraded forest land	A	A	B	B
		Include both emissions from and sequestration to forests in all national and global accounting of carbon stocks and changes in carbon stocks	B	B	B	B
		Reduce forest degradation and avoid deforestation	A	B	A	A
		Combine existing areas of multi-functional forests and reserves with afforestation with short-rotation coppice for bioenergy production	B	A	D	D
	O	Enhance forest growth and carbon sequestration through forest fertilization	B	C	D	B
		Modify thinning practices (timing, intensity) and rotation length to increase growth and turnover of carbon	A	A	D	B
		Minimize density of permanent road network and decommission and rehabilitate roads to maximize forest sinks	–	–	D	B
		Decrease impact of natural disturbances on carbon stocks by managing fire and forest pests	A	A	B	B
		Minimize soil disturbance through low-impact harvesting activities	A	A	B	A
		Enhance forest recovery after disturbance	B	B	B	B
		Increase the use of forests for biomass energy	A	A	C	C
		Practice low-intensity forestry and prevent conversion to plantations	B	B	D	B

Sources for adaptation options: BCMOF 2006a, FAO 2008, Garcia-Quijano et al. 2008, IPCC 2000, Kellomaki et al. 2005, Lemmen and Warren 2004, Nabuurs et al. 2008, Noss 2001, Parker et al. 2000, Spittlehouse 2005, Spittlehouse and Stewart 2003, Wheaton 2001, White and Kurz 2003.

Appendix 6.8 Potential strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining the health of people in forest-dependent communities. (Adapted from Colfer 2008a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Deteriorating health of forest-dependent peoples	S	Promote research on various aspects of forest foods	D	C	A	A
		Promote research on smoke inhalation	D	C	A	A
		Promote research on forest dwellers, their ill-health and their relationship to their environment	D	D	B	B
		Undertake systematic, comparative, longitudinal, holistic interdisciplinary studies on health and forests	B	B	B	B
		Promote research on the safety, efficacy and quality of medicinal plants	D	D	A	A
		Promote research on gender differences in health	D	C	C	C
		Recognize and address the interactions among environment, population, health, income generation, education and women's status	C	C	C	C
		Promote greater interaction/cooperation between environment and health sectors	A	A	A	A
		Promote interdisciplinary cooperation in health and forest interactions	A	A	A	A
		Develop better integration between traditional and modern health sectors	D	C	A	A

Impact	S/O	Adaptation Options	B	Te	S	Tr
	O	Dispense better education/information relating to health and use of traditional forest medicines	D	D	C	C
		Encourage policy changes that recognize the value of medicinal plants and integrate them with formal health-care systems	D	D	C	C
		Investigate and select appropriate certification and marketing networks for medicinal plants and producers	D	D	C	C
		Improve combined treatment and prevention	A	A	A	A
		Encourage the conservation and sustainable use of forest foods and medicines	A	C	A	A
		Develop new social understanding, new technology, new organizational approaches to prevent illness connected with smoke inhalation	D	C	A	A
		Enable greater accessibility to family planning in forested areas, for both human and forest well-being	D	C	C	C
		Reduce human contact with vectors, and improve disease recognition, epidemiology and biosecurity	D	B	B	B
		Encourage greater involvement of forest sector in sustainable forest management to benefit human health	D	A	D	D
		Develop closer, more effective partnerships between conservation and health professionals	D	C	D	D

Sources for adaptation options: Ali 2008, Allotey et al. 2008, Butler 2008, Colfer et al. 2006, 2008b, Cunningham et al. 2008, Dounias and Colfer 2008, Epstein 1994, Fowler 2008, Gonzalez et al. 2008, Kwa 2008, Lopez 2008, Pattanayak and Yasuoka 2008, Persoon 2008, Smith 2008, Vinceti et al. 2008.

Appendix 6.9 Strategic- and operational-level climate-change adaptation options that may be considered to achieve the management objective of maintaining and enhancing long-term multiple intangible socioeconomic benefits to meet the needs of societies. Adapted from Ogden and Innes (2007a).

Impact	S/O	Adaptation Options	B	Te	S	Tr
Changes in socio-economic resilience	S	Anticipate variability and change and conduct vulnerability assessments at a regional scale	A	A	A	A
		Enhance capacity to undertake integrated assessments of system vulnerabilities at various scales	B	B	B	B
		Foster learning and innovation and conduct research to determine when and where to implement adaptive responses	B	B	B	B
		Review forest policies, forest planning, forest-management approaches and institutions to assess our ability to achieve social objectives under climate change; encourage societal adaptation (e.g. forest policies to encourages adaptation, revision of conservation objectives, changes in expectations)	A	A	A	A
Erosion of local forest-related knowledge in forest-dependent societies	S	Support indigenous and local community efforts to document and preserve local forest-related knowledge and practices for coping with climatic variability and associated changes in forest structure and function	A	A	A	A
		Incorporate study of local forest-related knowledge into forestry and environmental education	C	C	C	C
		Promote research examining the underlying ecological bases of traditional forest and agro-forest management practices	C	C	C	C
		Encourage multidisciplinary, participatory research and dialogue between forest scientists and holders/users of local forest knowledge aimed at increasing adaptive capacity of both local and formal science-based approaches to sustainable forest management	C	C	C	C

Impact	**S/O**	**Adaptation Options**	**B**	**Te**	**S**	**Tr**
Changes in the frequency and severity of forest disturbance	S	Include risk management in management rules and forest plans and develop an enhanced capacity for risk management	B	B	B	B
		Increase awareness about the potential impact of climate change on the fire regime and encourage proactive actions in regard to fuels management and community protection	A	A	A	A
Human/ wildlife conflicts	S	Establish new mechanisms to enable the more peaceful co-existence of wildlife and people	D	D	D	D
Crop failure in climatically marginal agricultural areas	S	Reliance on forest products as a buffer to climate-induced crop failures	–	A	A	–
		Decentralization of local governance of resources i.e. the Community Based Natural Resource Management (CB-NRM) approach to promote use of ecosystems goods and services as opposed to reliance on agriculture	–	A	B	–

Sources for adaptation options: Agnoletti 2007, Berkes et al. 2000, BCMOF 2006a, Chapin et al. 2004, FAO 2008, Johnston et al. 2006, Kellomaki et al. 2005, Ohlson et al. 2005, Parrotta et al. 2008, Ramakrishnan 2007, Spittlehouse 2005, Spittlehouse and Stewart 2003.

7 Governance and Policies for Adaptation

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Abstract: The chapter presents a theoretical framework for the formulation and implementation of policies for adaptation, based on the policy design approach. Using this approach it evaluates traditional and new models of forest governance and policy instruments for the adaptation of forests and people to climate change. The chapter argues that traditional governance often fails to meet the challenges of inter-sectoral coordination posed by adaptation. The high level of uncertainty about the impacts of climate change on forests at the management-unit level supports new modes of governance based on policy networks and flexible policy instruments. The national forest programme is the core instrument of new forest governance at the national level; it can promote adaptation by reducing background levels of deforestation and forest degradation through sustainable forest management (SFM). It is proposed to add adaptation as an objective of SFM, within the dynamic balance of existing economic, ecological and social goals. From a policy design perspective, at the international level better integration of the biodiversity, forest and climate-change regimes is proposed in order to raise additional funds for SFM and to reduce emissions from deforestation and forest degradation (REDD). Finally, it is found that negotiations on SFM and REDD follow different strategies of social decision-making, from which specific recommendations for appropriate policy tools can be drawn.

Keywords: climate-change policy, forest adaptation policy, reduced emissions from deforestation and forest degradation (REDD), inter-sectoral coordination, policy integration, new and hybrid modes of governance, national forest programmes, international regimes on forests, regime integration, social decision-making

■

7.1 Introduction

Forests suffer from the direct effects of climate change as described in chapter 3. They also suffer from indirect effects of climate change – for example, the conversion of forests to bio-fuel crops. Correspondingly, 'adaptation' is understood as the adjustment of forests and people to direct and indirect climate change effects in ways which moderate harm or exploit beneficial opportunities. Although almost 20 years have passed since the publication of the first report of the Intergovernmental Panel on Climate Change (IPCC) about the detrimental effects of global warming caused by the emission of greenhouse gases (GHGs), the worldwide situation has worsened. The efforts to substitute fossil fuels by renewable energy have even increased the incentives for deforestation. As forests deliver many goods and services that help meet human needs, livelihoods are threatened if forests are adversely affected or even permanently cleared.

Forest-management measures to adapt to climate change can be supported by appropriate policy means that respect the central conclusions of chapter 6. In other words, policies will have to ensure flexibility for forest managers to respond adequately to the local conditions of the forest site, to accommodate indigenous knowledge and to consider the needs of local people regarding the provision of forest goods and services. These demands challenge the traditional nation state focusing on regulatory policy tools (command and control) and call for additional new models of forest governance based on negotiations between public and private actors. These negotiations will not be easy: while it is true that timber producers, environmentalists, indigenous people and other forest users all agree that forests should be protected against the impacts of climate change, they still disagree quite dramatically over how to do it.

National forest policy is also challenged by the international regime on forests. The regime comprises international negotiation processes in addition to forests, notably on biological diversity and climate change, all affecting forests. The negotiations within the international climate-change regime are of particular significance for forests and for the provision of forest ecosystem services because they aim at reducing emissions from deforestation and forest degradation and simultaneously support the longstanding efforts to combat deforestation in developing countries.

The main topic of this chapter is the evaluation of traditional and new models of forest governance for the adaptation of forests to climate change at the national and international levels. At both levels deliberations are critical for the coordination of conflicting interests. The focus will be on the following two questions:

- What policies and programmes are countries putting in place in forestry and related sectors to provide for effective adaptation to climate change and how well designed are these policies?
- What steps can be taken to strengthen forest governance to ensure maximum responsiveness to climate-change impacts on forests and people?

With respect to the distinctions developed in the broader climate-change adaptation literature, this chapter provides the outline of a normative policy assessment, recommending policy designs for reducing the vulnerability of forests and communities to climate change. It is necessarily incomplete, since, as the previous chapters demonstrate, the vulnerability assessments on which a full policy assessment will eventually be based have yet to achieve the necessary precision (Smit et al. 1999, Yohe and Toll 2002, Füssel and Klein 2006).

The subsequent text is divided into four sub-chapters. Sub-chapter 7.2 presents the theoretical framework for the formulation and implementation of policies for the adaptation of forests and people to climate change. It discusses the internationally agreed paradigm of sustainable forest management under climate-change conditions and the policy design approach for assessing the likely effectiveness of proposed policy tools. In the subsequent sub-chapters 7.3 and 7.4, which represent the centre-piece of this chapter, the main ongoing policy processes for the adaptation of forests to climate change at the national and international levels are assessed by matching them with the attributes of the policy design approach. Sub-chapter 7.3 discusses the key features of traditional and new environmental governance at the national level. Sub-chapter 7.4 deals with the main ongoing policy processes in the international regimes on biodiversity, forests and climate change. The conclusions in chapter 7.5 are drawn from discussing the results of the assessment through the policy design approach and lead to an overarching strategy of social decision-making for the adaptation of forests to climate change.

7.2 Theoretical Framework for the Formulation and Implementation of Policies for Adaptation

7.2.1 Paradigm of Sustainable Forest Management

Over the past two decades, the international forest-policy community has converged on a shared understanding of the broad goal of contemporary forest policy – what is sometimes called the policy paradigm – in the shape of sustainable forest management (SFM). SFM – or the management of forests according to the principles of sustainable development – has been formally adopted as an overarching goal for forestry by various international policy processes and agreements (including the United Nations Commission on Sustainable Development and United Nations Forum on Forests, UNFF) and as means to contribute to sustainable development, including the Millennium Development Goals. UNFF recognizes SFM as 'a dynamic and evolving concept that aims to maintain and enhance the economic, social and environmental values of all types of forests for the benefit of present and future generations'.

At the level of a broad, overarching goal, however, SFM remains a very abstract concept. Formulating and implementing policies to support SFM always require additional policy components. These components will include: a number of more concrete goals, sensitive to national and sub-national contexts; the general policy implementation preferences of the implementing institutions (usually, but not always, national governments) that will guide the choice of policy instruments; and the policy tools or instruments themselves that will be used to reach the policy goals (Cashore and Howlett 2007, Howlett and Kern 2009). Modifying SFM policies to include adaptation to climate change means adding adaptation to the existing list of concrete goals and choosing policy instruments that can achieve the new mix of goals without compromising the overarching commitment to sustainability. Can this be done and, if so, how?

Erkki Oksanen: Boreal forest, Finland

Photo 7.1 Sustainable forest management has been adopted as an overarching goal for forestry by various international policy processes and agreements and as a means to contribute to sustainable development.

7.2.2 The Policy Design Approach and the Problem of Policy Change

Our approach to this question is guided by two theoretical elements from the policy sciences literature. First, the problem is one of policy design. In a policy design approach (Linder and Peters 1984, deLeon 1990, Weimer 1992, Schneider and Ingram 1997), the policy process is understood as the practice of formulating and implementing appropriate programmes (outputs) in a continuous, open-ended process of aligning the following five attributes (Box 7.1):

- policy goals (both the overarching goal of SFM and the more concrete objectives)
- policy tools or instruments (or the means proposed to achieve the desired ends (e.g. the prohibition or encouragement of certain practices)
- the preferences and behaviour of implementers (or internal target groups), the public or private actors responsible for implementing the instruments (e.g. forest managers, international lenders)
- the preferences and behaviours of external target groups, those persons and institutions whose behaviour the adaptive forest policies intend to influence (e.g. forest users, consumers of forest products)
- rationales, the expressed justifications for the choice of goals and instruments, including the causal beliefs and theoretical connections between policy elements.

Box 7.1 Policies, instruments, programmes and designs

Usage of these key terms varies widely in the policy literature. This chapter uses the following definitions:

- Policies are decisions composed of two interrelated elements: policy goals and policy instruments (Lasswell 1958). Policy goals in this sense are the basic aims and expectations that organizations have when they decide to pursue (or not to pursue) some course of action.
- Policy instruments are the means used to achieve policy goals, the 'tools of government'. Once again a wide variety of classifications of policy instruments is found in the literature. This chapter uses the distinction between regulatory (e.g. legal regulations), market (e.g. subsidies, carbon trading) and informational (e.g. monitoring and reporting, research) policy instruments (Linder and Peters 1984, Hood and Margetts 2007). It also uses the distinction between substantive instruments that aim directly to affect behaviour, and procedural instruments, which aim to affect the way that policy itself is formulated (Howlett 2000).
- Programmes are specific instances of the implementation of a policy, sometimes involving single instruments, for example a funding programme, but often a mix of policy instruments.
- Policy design is an approach to policy analysis that gives a central place to evaluating the choice of policy instruments and the likelihood that a particular instrument or instrument mix will achieve policy goals (Salamon 1981). The policy design approach has generated a substantial body of knowledge about the origins, nature and capabilities of different policy tools (de Bruijn and Hufen 1998, Sterner 2003).

Thus the policy design approach allows the analyst to decompose a policy output into a set of attributes and to reconstruct and assess the 'intervention logic' of a programme. Are the policy goals internally coherent and do policy-makers understand how to make trade-offs between them if they conflict? Are the means chosen to achieve the goals consistent with each other and mutually reinforcing? Do the policy instruments conform to the general preferences of the internal target groups (e.g. for voluntary instruments or consensus processes) and are they likely to have the desired effects on external target groups?

Second, the problem is one of policy change. The early policy design literature often seemed to assume that designers begin with a clean slate and can invent and re-invent policies at will. This assumption is obviously false and 'policy legacies' will continue to act as significant constraints on the policy elements that can be adopted to achieve new goals such as adaptation.

There are several features of existing SFM policy designs that are relevant to and supportive of the addition of adaptation as a policy goal. The concept of SFM supports a holistic approach to forest management, spanning the three pillars of sustainable development – social, economic and environmental. The holistic approach promotes the goal of conserving forest biodiversity and hence supports measures that will maintain forest ecosystem services and facilitate risk reduction of climate-related natural disasters. Socially, it encourages the integration of forestry and forest policy with other land users in more comprehensive planning processes, which can include stakeholders in other sectors that will impact and be impacted by adaptation measures. Economically, SFM advocates a more equitable sharing of the benefits and costs of forest management amongst the various groups who use forest products. Finally, SFM represents a more collaborative, networked approach to the governance of forests at various levels, sub-national, national and international. Thus, the internal logic of SFM policy designs is highly compatible with adding adaptation as a concrete policy goal; the main challenge is that consensus-building becomes more cumbersome.

Politically, however, pursuing SFM goals and implementing SFM policies that facilitate adaptation of forests and people to climate change (see chapter 6) are much more challenging. Firstly, the forest-adaptation measures will have to be assessed for their impacts on other land users and resource sectors, and the reverse is also true. Lasco et al. (2008) provide an analysis of some cross-sectoral impacts of forest-adaptation measures on other sectors in a watershed in the Philippines. In order to minimize the negative impacts, the adaptation strategies could be prioritized on the basis of their effects on other sectors, so that those that have positive benefits on other sectors should receive higher priority and attempts should be made to alleviate any negative effects. Conversely, adaptive efforts in other sectors need to consider the impacts on forests and whether the overall impact is going to be positive. This poses new challenges to policy integration and planning.

Secondly, it is necessary to change target groups' preferences from short-term actions that jeopardize adaptation to medium- and long-term thinking. Most of the adaptation strategies require additional investments, which could pose a significant hurdle to their implementation. Finally, adaptation measures may change the balance between the benefits and costs of forest management itself. For example, if profit-oriented tree species are substituted by more resilient ones to ensure ecosystem services, the beneficiaries change. All this demands a readiness to include new participants and stakeholders into the forest-planning processes at all levels, creating new challenges to design appropriate multi-stakeholder processes that will include all those affected by adaptive strategies. Overcoming these constraints will require broader and more meaningful stakeholder participation and improved policy learning. While existing adaptation strategies rightly emphasize involvement (Lim et al. 2004), doing so will tax the institutional capacities of many countries and organizations. We turn first to an evaluation of how national policies are performing in these respects.

7.2.3 Types of Governance

As we learn from Chapter 5, current national policies involve a mix of regulatory, economic and informational policy instruments. However, we learn from Chapter 6 that forest policy should ensure appropriate mechanisms to enable the highest possible degree of flexibility of forest management on the ground: 'prescriptive approaches to climate change would be highly misleading, and most likely erroneous.' Forest policy 'must move away from prescriptive approaches to results-based approaches.' The conclusion must be that traditional governance, focusing on a hierarchical, top-down style of policy formulation and implementation of the nation state and the use of regulatory policy instruments, will be incompatible with this demand for flexibility. The precondition for successful use of regulatory and economic instruments is a degree of certainty about causation that is not present in the case of adaptation, as the scenario models in Chapter 3 clearly indicate. These levels of uncertainty rather support new modes of governance that appreciate the participation of multiple actors in the identification and implementation of policy goals by means of policy networks (see sub-chapter 7.3.2).

	Government determines societal goals (ends)	Society determines societal goals (ends)
Government selects the means of policy	**Traditional governance:** Hierarchical steering	Hybrid types
Society selects the means of policy	Hybrid types	**New governance:** Society itself is organizing

Figure 7.1 Types of governance (modified from Jordan et al. 2005).

Figure 7.1 provides a very simple typology of the main instrument types, delineated on the basis of who determines the ends and means of policy (Jordan et al. 2005). Of course, to apply new models of forest governance does not necessarily mean that they supplant traditional policy tools such as forest regulations, subsidies or tax exemptions; they are added to the policy mix. There is an additional aspect that limits the role of traditional forest governance: internationalization. National forest policy is affected by a series of international negotiation processes on forests (see sub-chapter 7.4).

7.3 Policy Instruments at the National Level

7.3.1 Traditional Instruments

In Chapter 5 it was noted that the main purpose of traditional regulation is to maintain forest cover by proscribing deforestation and prescribing reforestation after harvest. These regulations are typically supported by further phytosanitary prescriptions and economic incentives to correct market failures. This policy mix has formed the backbone of traditional forest policy, it continues to influence contemporary understanding of SFM and is currently assumed to provide a sufficient policy framework to cover adaptation to the impacts of climate change as well. However, the current state of climate change modelling cannot yet produce accurate predictions of climate change impacts on the ground at scales that are useful to forest managers. We take this level of uncertainty to support a more flexible precautionary approach to forest management than traditional prescriptive regulation can provide.

Policy design under these circumstances must take careful note of such lack of specific information and the limitations of the data in the choice of appropriate policy instruments. In addition, calls for the use of risk assessment tools to determine vulnerability must take into consideration the normative nature of risk assessment under these conditions of uncertainty. Finally, it is clear that there are considerable disparities of power and resources amongst the groups subject to traditional regulation, particularly in developing countries, which accounts for the uneven success of the traditional regulatory approach in these countries. Policies designed to correct these governance failures call for an instrument mix that addresses the widest range of alternative data sources, the inclusion of multiple actors in carrying out risk assessments, and representation of all target groups in decision-making and the formulation of new policies. New and hybrid modes of governance are required.

National Adaptation Programmes of Action (NAPAs)

National Adaptation Programmes of Action (NAPAs) are prepared by the least developed countries with the goal of identifying priority activities that deliver their urgent and immediate needs in adaptation to climate-change impacts. The rationale rests on the limited resources of these countries to adapt to the adverse effects of climate change. The main instrument is the provision of financial means by the Global Environmental Facility (GEF) and GEF-related other funds (see 7.4.3) for projects proposed by the NAPA. The NAPA documents also present overviews of projected climate change and associated adverse effects. The sectors considered include land-use management and forestry. However, there is evidence that the countries are not drawing on the available resources, probably because they have a different view of the urgency of adaptation to climate-change impacts in comparison with their other Millennium Goals (Simula 2008).


John Parrotta: Central Malawi

Photo 7.2 NAPAs are prepared by least developed countries to identify priority activities that respond to their urgent and immediate needs in climate change adaptation. They focus on land use management and forestry.

For NAPAs to become really effective policy instruments, their preparation should be well integrated into the mainstream national development planning and decision-making. The design process should also be made more participatory in order to ensure that the perspectives of all stakeholders/actors are incorporated.

National Adaptation Strategies

In other developing and developed countries, where the challenge is less lack of resources than improving inter-sectoral coordination and high-level policy integration, national adaptation strategies are, again, potentially appropriate policies. In the following, Finland's National Strategy for Adaptation to Climate Change (Ministry of Agriculture... 2005) is taken as an example for similar strategies of other developed countries (e.g. United Kingdom, Spain, China). The objective is to strengthen and increase Finland's capacity to adapt to adverse impacts of climate change by describing the impacts on the main affected sectors; assessing their adaptive capacity, vulnerability and opportunities associated with climate change; and presenting immediate actions and policies for future actions. The underlying rationale is the precautionary principle for reducing the risks of adverse effects of climate change. 'Because of the inertia involved in climate change, today's decisions and actions will have impacts far into the future.' (Ministry of Agriculture... 2005, p. 10). In 2003, the Finnish Parliament established a task force with representatives from the participating ministries, with the Ministry of Agriculture and Forestry as coordinator and supported by relevant research institutes. The draft was sent to a number of stakeholders for comment; the public respond through the internet. The core of Finland's National Adaptation Strategy is indicative adaptation measures for the most relevant sectors, divided into short-term (2005–2010), medium-term (2010–2030) and long-term (2030–2080) measures. In addition, emphasis is put on cross-sectoral issues, such as coordination and cooperation between different branches of public administration (sectoral, regional and local authorities), institutions and actors. The policy tools available to authorities include regulatory means, economic-technical measures, and informational means such as planning, environmental impact assessment, risk management, observation and warning systems, research and education.

From a policy design perspective, the major shortcoming of the Finnish National Adaptation Strategy (NAS) has been the technocratic policy-making process at the governmental level. Thus there are no concrete proposals for policies that could mitigate inter-sectoral conflicts; they are left to resolution in the 'shadow of hierarchy' (Scharpf 1993). Because deliberations on the Strategy were not devised as an open-ended process, there is very little chance of policy learning by the participants over the course of time. When revisiting the Strategy, societal interests may be included, and this may begin to transform the Finnish NAS into a hybrid or new mode of governance as described below in sub-chapter 7.3.2.

Inter-Sectoral Coordination

Similar considerations about the importance of meeting information needs for effective use of traditional policy instruments also apply to the use of economic instruments such as financial incentives and disincentives. We will not repeat these arguments for the case of incentives. However, information needs are less significant in a third area of traditional governance activity, inter-sectoral coordination. Decisions in the forest sector are not only influenced by forest policy. Many actions taken with regard to forests occur as a result of policies elsewhere in the economy. Policies in other sectors may directly or indirectly, intentionally or unintentionally influence decisions affecting forests, sometimes more so than forest-sector policies themselves (Thompson and Christophersen 2008, World Bank 2004, Schmithüsen 2003) (Box 7.2). This is critical in the context of adaptation to climate change as policies in other sectors may reduce the adaptive capacity of the forestry sector and impede its ability to cope with climate change. The adaptive capacity of both natural and planted forests will be enhanced by policies which support and maintain the forest rather than policies which encourage deforestation. It is generally assumed that a given degree of forest structural and biological diversity at various scales is necessary for maintaining the adaptive capacity of forests to environmental change (Guariguata et al. 2007, Noss 2001). Thus, there is a continuing role for traditional coordination, and two sectors are particularly important for adaptation of forests to climate change: agriculture and energy.

Agricultural Policy

Policies in or affecting the agricultural sector, both in response to climate change and agricultural policies in general, may have the greatest influence on forests. Changes in climate which affect agricultural production may drive farmers into new areas, resulting in the clearing of forest for agricultural land. Policies designed to support the agricultural sector under climate change may exacerbate this. However, policies completely unrelated to climate also have the potential to lead to deforestation and ultimately weaken the capacity of the forest sector to adapt to a changing climate. Any policy or change in conditions which makes alternative land uses more profitable relative to forestry creates incentives for deforestation, undermining the ability of the forest sector to adapt to climate change.

A national policy that changes the price or quantity of agricultural commodities has the potential to

Box 7.2 Coordination, integration and interaction

As policy goals become more numerous and more complex, policies begin to lose their ‘single issue’ character and interact in various ways with initiatives in other policy areas that were once thought to be quite distinct. For example, when forest policy was largely concerned with growing commercial wood fibre in production forests, forest policy could usually be conducted without much reference to developments taking place in agriculture, tourism and recreation, and energy and infrastructure policies. As forest policy has embraced more numerous and more complex goals, such as biodiversity conservation, poverty alleviation, the protection of indigenous rights and now adaptation and mitigation of climate change, it has become clear that policy development in these other areas will have a major impact on the ability of forest managers to meet forest policy goals and vice versa. The set of new problems created takes three distinct forms which, for the sake of consistency, are referred to by three distinct terms throughout this chapter:

- Inter-sectoral coordination is the challenge of ensuring that policy development in related policy sectors at the national level is not contradictory or counterproductive; for example, that financial incentives are not being provided for converting forests to agricultural land at the same time as forest managers are trying to prevent deforestation (Peters 1998).
- Policy integration is the attempt to bring a new goal into an existing policy framework so that all elements of the policy framework reflect that new goal. Integration may be very ambitious; for example, the efforts to achieve environmental policy integration so that any new policy in any policy area is assessed for its environmental impacts. The attempt to bring adaptation to climate change into the SFM framework is a less ambitious example of policy integration. It can take place at the national or the international level (Briassoulis 2005).
- Regime interaction takes place when international policy regimes, such as SFM, biodiversity conservation and climate change, have overlapping goals. Ideally, the interaction will be mutually reinforcing but sometimes the effects are contradictory and need careful analysis and design. For example, some forest non-governmental organizations (NGOs) have drawn attention to the apparent contradiction between the Convention on Biological Diversity’s emphasis on in situ conservation of biodiversity and the incentives provided for plantation forestry by elements of the Climate Change Convention (Gehring and Oberthür 2004).

induce changes in deforestation and land use even when the policy is not directly related to agriculture (Coxhead et al. 2001, World Bank 2004). Forest degradation and loss are often the result of polices and agendas generated far away from the site of concern (Rudel 2005). Theoretical studies have shown that an increase in agricultural prices, through mechanisms such as subsidies, exchange-rate policies and trade policies, accelerates agricultural expansion because, as farming becomes more profitable, farmers allocate more inputs to clear forests (Kaimowitz and Angelsen 1998, Takasaki 2007). Recent studies in Sumatra showed that rates of forest clearing increase when global coffee prices rise, as local coffee growers expand their land to plant more coffee (Kinnaird et al. 2003). A study of the Brazilian Amazon confirmed the negative impact on forests of measures that made agriculture more profitable. The measures ranged from currency devaluations to investments in roads that reduced transportation costs. A 20% reduction in transportation costs for all agricultural products from the Amazon, for example, was predicted to increase deforestation by approximately 15% in the short run and by 40% in the long run (or about 8000 sq km deforested annually) (Catteneo 2002). Essentially, any measure which renders agriculture more profitable can increase incentives to clear forests for farmland, and it is probable that in some countries agriculture will receive support for adaptation to climate change. It is therefore critical that communication between the agriculture and forest policy sectors is strengthened and that the likely economic, social and environmental impacts of deforestation are fully considered when climate-related policies in the agricultural sector are being formulated to make well-informed policy decisions.

While trade and price-distorting agricultural policies require attention at the level of international negotiations, policies that promote the adaptation of forests to climate change can be introduced at both the national and the local level. At the national level, the complex interactions between macroeconomic policies and sectoral policies suggest the utility of 'mainstreaming' climate-change policy, including adaptation strategies, as a way of alerting policymakers to the negative impacts of policy changes proposed in other sectors. At the local level, there are often a variety of context-specific factors that are already promoting deforestation that can be addressed on a case-by-case basis. Catteneo (2002), for example, estimates that forest clearing as a means of establishing fraudulent land claims is a significant factor in promoting deforestation in Brazil, and that the deforestation rate could be reduced by as much as 23% if land claims were properly verified and violators evicted.

Energy Policy

Forests and energy are closely interlinked. Forests are a source of renewable energy, both biofuel and biomass energy. Forests also occupy land which may be used to grow other types of biofuel crops. The way in which these sources of carbon are governed has important implications for the forests. As with agricultural policies, any policy which increases the profitability of another sector relative to forestry may result in deforestation.

Energy policies to reduce dependence on fossil fuels and emissions of CO2 have resulted in the growing popularity of biofuels. Several countries now have minimum targets for biofuel use. In the short- to-medium term, biofuels are seen as a promising option to reduce greenhouse-gas emissions while improving the security of energy supplies (EU Commission 2007). Industrialized countries are increasingly dependent on biofuel imports from developing countries, for example from Brazil, Indonesia and Malaysia. Unless environmental values are adequately priced, there are powerful incentives to replace forests, and other ecosystems, with dedicated bioenergy crops (Doornbusch and Steenblik 2007). This has resulted in the removal of forests for biofuel production. This has the double effect of causing further emissions through deforestation, as well as making adaptation in the forest sector more difficult.

Besides the GHG balance, other environmental impacts need to be carefully considered when promoting energy policies. Impacts on soil degradation, resource depletion, biodiversity loss, ecotoxicity, air pollution and on water contamination have been included in a study using the Life Cycle Analysis framework (LCA) (Zah et al. 2007). According to the report, the environmental effects of the production of almost all biofuels are more harmful than those of fossil fuel production. If so many livelihood assets are negatively affected, it is likely that the overall adaptive capacity of the whole ecosystem – including natural and social systems – will be reduced. Furthermore, sustainable forest management practices sequester more carbon over a 30-year period than the emissions avoided by the use of biofuel with current technology (Righelato and Spracklen 2007). Second-generation biofuels may prove to be more efficient, but may still compete for forest land and threaten the adaptive capacity of forest systems.

Other forms of energy generation may also compete with forest land. Renewable energy such as hydropower may promote the flooding of lowland valleys and forests as an alternative to fossil-fuel consumption. The displacement of communities living in and/or relying on forests will reduce the overall resilience of the system and may lead to problems in other areas or sectors.

John Innes: Oil palm plantation eastern Sabah, Malaysia

Photo 7.3 In recent years, there has been an increase in oil palm plantation establishment in an effort to meet the growing demand for biofuels.

The evidence presented in the previous sections above already suggests that inter-sectoral coordination is a more complex subject than usually understood. Developments in the energy sector clearly have implications for both forestry and agriculture. Developments in a number of other sectors have similar effects. Considerations such as these cast doubt on a traditional sector-by-sector approach to coordination and suggest the need for a more holistic approach. We find such an approach in new and hybrid modes of governance.

7.3.2 New and Hybrid Modes of Governance

As described in Figure 7.1, the traditional mode of governance gives way to hybrid and new policy designs when new participants enter the forest policy process. For example, national forest policy is affected by globalization, reducing the ability of national governments to affect outcomes in their own jurisdictions (Howlett and Rayner 2006). Forest-management planning is unable to cope with complex issues and the presence of multiple actors seeking to achieve their own goals. Implementation deficits are commonly observed in the form of disappointing results and unintended consequences on the ground.

The idea of new governance originated from the perceived failure of nation states' preference for top-down policy-making. New governance models seek to embrace complexity and turn the presence of multiple actors from a problem into a solution. They appreciate the participation of multiple actors in the identification and implementation of policy goals. In the new governance relationship, the complexity of the problem area is matched by a form of organization that copes better with complexity: the policy network. 'Networks are loosely coupled groups of private and public actors, characterized by the recognition of mutual dependence in order to achieve their goals. Mutual recognition leads, in theory, to rapid exchange of resources, especially information about policy impacts, unintended consequences and unanticipated problems. In this sense, governance through policy networks [network governance] is part of the more general effort to empower civil society to regulate itself' (Glück et al. 2005, p. 54). Policy networks are increasingly international in scope, mirroring developments in global forest policies.

Network governance, as well as other approaches of new environmental governance, has been put forward by Agenda 21 (UNDESA 1992). They integrate the following approaches: long-term planning, target and results-oriented governance, environmental integration, cooperative governance, and participation and monitoring (Jänicke and Jörgens 2006). The application of these approaches, supplemented by multi-level governance and decentralization, to policies for the adaptation of forests to impacts of climate change at the national level, are discussed below.

Long-term adaptive planning: Adaptation of forests to impacts of climate change requires short-, medium- and long-term actions. Short-term actions are needed after extreme events and disturbances to provide the affected people with the most important things for survival. Fast and targeted actions are facilitated by a disaster action plan developed before the event has occurred. The disaster action plan does not only comprise a checklist of appropriate actions, but also has to ensure access to the necessary resources for protecting people during the first days until effective help comes from outside. In the medium term, the disaster action plan may contain practical advice about the adjustment to the timber market after heavy wind damages, for example, to remove the felled timber from the market and store it in irrigated timber yards, access to subsidies for reforestation with appropriate species, etc. In the long-term reliable prediction models (see Chapter 3), research about the impacts of climate change on the forest and appropriate forest-management measures are proposed. For the potentially affected people, it is important that the anticipatory measures are taken in time.

Target and results-oriented governance: The necessary forest-management measures and adaptation policies are drawn from observed and predicted vulnerabilities and future impacts of climate change on forests on the basis of approved prediction models. Target setting involves a learning and consensus-building process that makes actions likelier and breaks down resistance among affected parties. The proposed approaches should build upon the interests of forest managers and the affected people and require a realistic stance on dealing with foreseeable obstacles. The focus should be on key targets and a limited number of strategic goals; it is necessary to set priorities.

Environmental integration by inter-sectoral (horizontal) coordination: Climate-change policy aims at mitigation of GHG emissions and adaptation to climate change. Mitigation policy strives for changes in energy policy, transport policy, agricultural policy, forest policy, etc. But adaptation of forests to climate change also requires coordination with forest-based mitigation measures, as well as with mitigation and adaptation policies in other sectors. In both cases inter-sectoral coordination is impeded by traditional 'negative coordination' (Scharpf 1993, Hogl 2002a) that impinges as little as possible on the vested interests of affected sectors. Sectors endowed with considerable lobbying power, such as farming in developing countries, can exert severe pressure on forests and involve path dependencies. Yet, inter-sectoral coordination is possible, either within hierarchic structures ('coordination in the shadow of hierarchy') or by negotiations in networks (Scharpf 1993, Hogl 2002a).

Cooperative governance: State actors regard private-sector target groups as essentially equal partners and build policy networks. They expect the following assumed benefits (Jänicke and Jörgens 2006): better targeted policy than regulation by legislative decree; government departments are interested in legitimizing their actions; less opposition when measures come to be implemented; parliamentary decision-making processes are by-passed and adaptive processes such as innovations can be stimulated earlier; 'soft', communicative and hence more readily accepted policy instruments can be applied while 'harder' policy tools (command and control) remain available.

Participation: The FAO/ECE/ILO* Joint Committee Team of Specialists on Participation in Forestry (2000, p. 9) defines participation as 'a voluntary process whereby people, individually or through organized groups, can exchange information, express opinions and articulate interests, and have the potential to influence decisions or the outcome of the matter at hand.' Efficient participation also requires a procedure resting upon transparency and fairness. This calls for a structured process, a framework and a political dialogue facilitated by equality between different stakeholders (Appelstrand 2004).

Monitoring: Monitoring and reporting aim at periodically collecting data on politically relevant issues. The data serves as a basis for policy-making, and political actors often contest which data to monitor and publish, which survey approaches and survey intervals to apply, etc. In the context of adaptation of forests to climate change, data on SFM, impacts, vulnerabilities, afforestation, reforestation, deforestation and forest degradation are crucial (see Chapter 5). As monitoring and reporting cause substantial additional cost for surveys, they can easily be refused for economic reasons.

Multi-level governance (vertical coordination): Environmental governance does not only take place at the national level, but also at the sub-national and international levels. The relationships between these different layers are characterized by mutual interdependence on each others' resources. The decision-making process in systems with several separated but interdependent arenas

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* Food and Agriculture Organization of the United Nations / United Nations Economic Council for Europe / International Labour Organization

(e.g. national and sub-national) are characterized by the following dilemma: The decision-makers at the sub-national level have to cooperate at the national arena and, simultaneously, at the sub-national arena pursue specific interests defined by their responsibilities or constituencies. In such situations, actors tend to refer to conflict-avoiding strategies, soft norms or vague decisions avoiding interference with powerful interests (Hogl 2002b).

Decentralization: Decentralization is defined as 'the transfer of powers from central government to lower levels in a political-administrative and territorial hierarchy' (Agrawal and Ribot 1999 quoted in Glück et al. 2005, p. 61). One expects from decentralization the creation of interdependent bottom-up policy networks which ensure SFM and reduce deforestation and forest degradation. The underlying rationale is that local authorities represent local population better because they have better knowledge of local needs. When they are endowed with powers, in particular with discretionary powers over public resources, they are more likely to respond to local needs than a distant central authority (Ribot et al. 2004). However, in case studies about the decentralization reform in Senegal, Uganda, Nepal, Indonesia, Bolivia and Nicaragua, it was found that the local authorities either lacked control over significant levels of resources or shared accountability with a series of other actors who cannot be made accountable (Schroeder-Wildberg and Carius 2003, Ribot et al. 2004). Decentralization has not always promoted a more sustainable management of the forest resources or the empowerment of local communities (Colfer et al. 2008).

National Forest Programmes

The core instrument of new forest governance at the national level is the national forest programme (NFP). The term 'national forest programme' is a generic name for a wide range of approaches towards forest policy formulation, planning and implementation at the sub-national and national levels. As one of the most important outcomes of international forest policy dialogue, the NFP is a commonly agreed framework for sustainable forest management which is applicable to all countries and to all types of forests. The NFP is a country-specific process that provides a framework and guidance for: country-driven forest-sector development; for national implementation of internationally agreed concepts (such as sustainable forest management) and obligations (e.g. UN conventions), and for external support for forest-related development cooperation.

The goal of NFPs is the sustainable management, conservation and sustainable development of a country's forests so as 'to meet the local, national, regional and global needs and demands of the present and future generations' (UNCED 1992). Adaptation to the impacts of climate change will be added to these goals, and the challenge will be to overcome both the internal and external constraints to the achievement of the existing goals created by the new one (see 7.2.2.).

The main instruments used by NFPs are all relevant to realizing the goal of adaptation. They are: participation of the relevant actors in the policy-making process instead of hierarchical governing; adaptive and iterative learning processes instead of long-term, scientifically poor forecasts; comprehensive ('holistic') inter-sectoral coordination of actors; and decentralization in order to facilitate the implementation of policy outputs. Many of these instruments are employed in traditional governance. However, in a new governance approach, the single-instrument approach is set aside in favour of considering a mix of mutually supportive instruments. For example, traditional inter-sectoral coordination of the kind described above takes a sector-by-sector approach. A well-designed NFP will attempt holistic coordination amongst all relevant sectors. Similar ideas are also found in other new governances approaches (Box 7.3).

Box 7.3 Adaptive governance

'Adaptive governance …focuses on reflexivity and learning by doing, on the most vulnerable systems that include both human and ecological systems and on the forms of collaboration and partnerships, knowledge, social learning and forms of engagement. The four basic conditions that underpin adaptive governance include: to build knowledge and understand resource and ecosystem dynamics, which requires incentives and human capacity to monitor and translate signals; to feed ecological knowledge into adaptive management processes, whereby successful management includes continuous testing, monitoring, re-evaluation rather than optimizing based on past records; to accept uncertainty and be prepared for change and surprise, i.e. institutions are prepared for both ecosystem management changes and unpredictable changes brought about by climate change (e.g. storms, hurricanes, pests, disease outbreaks); and to support flexible institutions and multilevel governance systems through networks, operationalized through adaptive co-management, which is adaptive management with multiple level linkages and bridging organizations.' (Boyd 2008, p. 1914).

The real challenge posed by adding adaptation goals is the addition of new actors and hence the additional burden of consensus-building. In other words, adaptation creates external constraints on what can be successfully adopted as an NFP. The implementation of the principles of an NFP requires the establishment and maintenance of a climate of mutual trust, where the participants are prepared to remain at the negotiation table and to regard the dialogue on forest issues as an open-ended process (Glück et al. 2005, Zingerli and Zimmermann 2006). The more participants, the more difficult this will be.

Main Challenges to NFPs

Compared to the general goals of SFM, which drive NFPs, combating climate change has deferred questions of the specific objectives that should be achieved. However, on the basis of the IPCC reports, combating climate change is characterized by more agreement on causation. For example, the objectives for reduced deforestation and forest degradation were not included in the Clean Development Mechanism (CDM) of the Kyoto Protocol (KP). NFPs, by contrast, are specifically designed to enable participatory discussion of goals. The ongoing discussions out of which criteria and indicators of SFM have emerged provide the best example. While there is still disagreement about the best way to implement SFM, widespread agreement on specific objectives has been achieved. Adaptation to climate-change impacts urgently needs such consensus on goals, such as targets for reducing deforestation and criteria of forest health or integrity. NFPs could produce them.

Empirical evidence suggests that most NFP processes continue to restrict participation. This is the main obstacle for NFPs to achieve their promise with respect to adaptation. These restrictions should be removed as much as possible by a code of conduct that regulates the access of all interested parties as well as all organizational and procedural aspects of the negotiations, especially the decision rules. Dissenting positions must be recorded and should be considered in future rounds of negotiations. As participation in a NFP process will normally be time- and resource-consuming, actors who are well endowed with resources are likely to be favoured. Potential losers in the process are also reluctant to participate, suggesting the need for subsidizing participation. In federal states the different division of forest-related affairs (e.g. forestry, nature conservation, agriculture) between national and sub-national responsibilities can be another reason for non-participation that may be more difficult to address.

In the real world, the switch from traditional to new forest governance is not at all self-evident for the participants. There is always the inherent possibility that the outcome of NFP processes is only 'symbolic' in terms of the core instruments (participation, long-term iterative planning, inter-sectoral coordination and decentralization). The formulation of a substantive NFP depends on impeding and supporting factors (Glück et al. 2003, Humphreys 2004). An impeding factor is one that inhibits or constrains the substantive development of these core instruments, while a supporting factor is one that contributes to the substantive development of the core instruments of a NFP. Substantive and impeding factors of NFPs are land tenure, financial incentives and political culture.

Land Tenure

Secure land tenure and forest user rights are an indispensable precondition for the private sector, local communities and smallholders to invest in SFM. 'Tenure helps to determine whether local people are willing to participate in the management and protection of forests' (Banana and Ssembaajjwe 2000, p. 93). Private and common property regimes enable the holders of private ownership rights to use the forest in their own interest, to protect it against impacts from outside and to adapt to unavoidable impacts of climate change. Public-sector ownership is not necessarily a supporting factor. In Greece, state forest ownership has empowered forest authorities to make decisions for the greatest collective good of society but blocked the meaningful participation of other stakeholders (Humphreys 2004). Community forests are managed by local administrations on public land; the revenue from the sale of forest products from these forests is shared among the members of the community in cash, in-kind or in the form of infrastructural development. In developing countries Ccommunity forests play an increasing role forin SFM in developing countries (e.g. Wood and Yapi 2004, Lee 2007a and Lee 2007b).

The communities regard the forest as an integral source of their livelihoods and are prepared for long-term investments if the tenure rights are secure. Secure rights are a necessary condition but not a sufficient one. What is most important is the actual contribution of forests to peoples' livelihoods: 'The hypothesis that people benefit from the forest, and would conserve it if they controlled it, may not hold when alternative land uses provide higher benefits than forests.' (Tacconi 2007, p. 343). Similar to community forestry is leasehold forestry; the major difference is that in the latter, individuals are given user rights to plots of forest land. Leasehold forestry in Nepal provides 40-year leases for small plots of degraded forest land to the poorest of the local people. In Ethiopia, leasehold forestry refers to the establishment of communal forest user rights on communal lands whereby the poorest members of the local community are provided with patches of degraded land for a certain period of time (usually 25 years) for the purpose of tree planting. This programme has proved to be an extremely effective measure for environmental regeneration, although it is based on local institutional arrangements and does not have any legal protection and policy ground (Tesema 2008). The most detrimental form of forest ownership is open access when public forests are not actually regulated and legal ownership rights are not exercised. Such forests are difficult to protect and easily depleted. They are exposed to the 'tragedy of the commons' (Hardin 1968) unless institutional arrangements such as allocation of user rights and establishment of common property regimes are put in place.

Financial Incentives

Financial incentives or disincentives for SFM come either from the national finance ministry (e.g. subsidies, grants, taxation, tax exemptions), bilateral Official Development Assistance (ODA), multilateral sources (World Bank Group), private-sector investments, NGOs, philanthropic foundations and other sources. Financial instruments play a crucial role in affecting actor behaviour; they can support or impede SFM depending on how they are designed. For example, high inheritance taxes in Flanders have impeded SFM and caused forest owners to lose interest in forest-management issues. But financial incentives act as a supporting factor in the United Kingdom, Lithuania and Switzerland (Humphreys 2004).

Payments for environmental services (PES) offer a relatively new source of financial support for SFM (FAO 2007). Costa Rica was a pioneer in developing a payment for environmental services mechanism. In 1996, it initiated a programme that enhances various forest environmental services (e.g. carbon sequestration, hydrological services, biodiversity conservation and provision of scenic beauty) through compensation payments to land and forest owners in exchange for multi-year contracts for reforestation, sustainable forest management and forest protection. Mexico has also recently initiated a national PES programme for forest-based environmental services. The growing role of the PES approaches today reflects underlying changes in environmental policy and the private sector worldwide. Hundreds of PES schemes are now being implemented, in both developing and developed countries, primarily for forest-based environmental services. A global review conducted by Landell-Mills and Porras (2002) examined 287 cases of market-based initiatives in the forest sector.

Political Culture

Political culture can be described as the sum of the fundamental values, instruments and knowledge that people of a country or parts of it share; they are acquired through political socialization and give form to political process. Political culture is an integral part of political reality and determines, among others, what and how issues are regulated. The patterns of political culture determine interest-oriented actions. Policy-makers have the choice to take certain accepted actions but not others. They can hardly break out of the established patterns of action without jeopardizing their success. Finally, political culture determines what is regarded as an issue (Berge 2004). For example, in Lithuania the old political leftovers from the previous centrally planned economy still linger. The Portuguese report suggests that such transitions can take decades. In Portugal the authoritarian political culture of half a century continues after the restoration of democracy in 1974. This has tended to impede inter-sectoral coordination and participatory decision-making. The French political culture is characterized by emphasis on representative rather than participatory democracy. Senior public officials and experts play a leading role in national policy processes, also in forest policy. There is a similar situation in Greece where the public authority is regarded 'the sole entity in charge of making choices in the interest of the common good' (Humphreys 2004, p. 27). The political cultures of France and Greece are obstacles for participatory networks. Also a strong clientelist or corporatist tradition in policy-making can impede genuine participation from other stakeholders (Ollonquist 2004). Other political cultures, however, are more supportive of direct public participation, such as that of Switzerland.

7.4 New Forest Governance Processes at the International Level

7.4.1 Introduction

During the past decades, a series of international agreements on forests – legally binding and non-legally binding – has been achieved; it forms the 'international regime on forests'. The following section discusses the main instruments used to adapt forests to the impacts of climate change in the light of the attributes of the policy design approach. The international regime on forests accrues additional significance due to climate change. The unresolved issue of deforestation not only exacerbates poverty in many developing countries but also increases GHG emissions which adversely affect various sectors of other countries.

On the other hand, deforestation is driven by factors that are not always under the control of the country. These inter-sectoral issues caused by failures of nation states have arrived at the international political agenda and are dealt with by various international institutions. One of these topics is reduced or avoided deforestation. It simultaneously mitigates climate change through carbon storage and contributes to the adaptation to impacts of climate change. The analysis of the main international instruments should contribute to a better understanding of possible solutions for the adaptation of forests to impacts of climate change. The analysis is organized according to the following three components of the larger international regime on forests: United Nations Convention on Biological Diversity as the main part of the international biodiversity regime; selected elements of the international forest regime of relevance to adaptation (comprising the Non-Legally Binding Instrument on All Types of Forests, The International Tropical Timber Agreement, Forest Law Enforcement, Governance and Trade,ITTA, FLEGT, forest certification and the World Bank Strategy); and the climate change regime with the United Nations Framework Convention on Climate Change and its Kyoto Protocol, including reduced emissions from deforestation and forest degradationREDD.

7.4.2 The International Biological Diversity Regime

The Convention on Biological Diversity (CBD) was adopted by the UN Conference on Environment and Development (UNCED) in June 1992 in Rio de Janeiro (‘Earth Summit’) and entered into force in December 1993. The Convention has the following three main goals: conservation of biological diversity (or biodiversity); sustainable use of its components; and fair and equitable sharing of benefits arising from genetic resources. The main challenge to a successful design involves addressing the general market failure to value biological services and will necessarily involve the provision of financial incentives and compensation. Adaptation will put new strains on the ability to provide this financial assistance through the Global Environmental Facility, which is already subject to a number of other demands. The Ad Hoc Technical Expert Group on Biodiversity and Climate Change (AHTEG) was established in 2008 with a mandate to develop advice on biodiversity, relevant to the Bali Action Plan and the Nairobi Work Programme (see sub-chapter 7.4.3).

The primary framework for action under the Convention is the ‘ecosystem approach’; it will help to reach a balance of the three goals of the CBD. It is similar to the concept of SFM as both are based on the tenet of sustainability. Decision V/6, Annex 2, of CBD-COP 7 in 2004, Kuala Lumpur, states that ‘SFM can be considered as a means of applying the ecosystem approach to forests’. It is an example of positive interaction between international regimes (see Box 7.2). As a result, both are overarching frameworks with due consideration to societal, ecological and governance issues. Whereas the ecosystem approach is content-driven based on 12 principles, SFM is outcome-driven and can be measured by criteria and indicators (C&I).

In regard to the adaptation of forests and people to the impacts of climate change, the implementation of the CBD is supported by C&I of SFM at the national level (by monitoring and reporting) and management-unit level (by forest certification schemes). In order to achieve greater harmonization of the SFM and ecosystem approach and to strengthen cross-sectoral integration, Decision V/6 proposes to apply C&I tools to other sectors. C&I, for sustainable agriculture in particular, could help abate forest degradation and deforestation. Similarly, forest C&I should include specific indicators of vulnerability to climate-change impacts and for the resilience of forests and forest-dependent communities.

7.4.3 The International Forest Regime

The Non-Legally Binding Instrument on All Types of Forest

In 2006, the UN Forum on Forests (UNFF) agreed on a new resolution, valid until 2015, to establish a Non-Legally Binding Instrument on All Types of Forests (NLBI). The NLBI, negotiated in April 2007 and adopted by the UN General Assembly in December 2007, superseded 270-odd ‘proposals for action’ that were the output of the IPF (Intergovernmental Panel on Forests) and IFF (Intergovernmental Forum on Forests) processes, and built upon the UNFF resolution. Under the overarching goal of SFM, the NLBI establishes objectives and policies to promote SFM at the international, regional and national levels. Together with its associated work programme, the NLBI prescribes and gives guidance for the implementation of four global objectives set out in the UNFF resolution. They are: (i) reverse the loss of forest cover; (ii) enhance forest-based economic, social and environmental benefits; (iii) increase significantly the area of protected forests worldwide and other areas of sustainably managed forests, as well as the proportion of forest products from sustainably managed forests; and (iv) reverse the decline of official development assistance for SFM.

The International Tropical Timber Agreement (ITTA)

When this successor agreement to the ITTA 1986 and ITTA 1994 enters into force, it will be the only binding agreement with the specific objective of promoting the sustainable management of forests, albeit covering only tropical timber-producing forests and only in the context of promoting 'the expansion and diversification of international trade in tropical timber from sustainably managed and legally harvested forests'. Thus its trade-related limitations are clear. It funds specific projects as well as helps to build capacity through the multiple-level evaluation, monitoring and review that each project must undergo. The new Thematic Programmes Sub-account under the ITTA 2006 holds potential for increasing funding as well and using it more efficiently. Currently the International Tropical Timber Organization (ITTO) is developing a thematic programme area on how to include climate change, regarding both mitigation and adaptation, into its working packages.

Forest Law Enforcement, Governance and Trade

The European Union adopted in 2003 the Action Plan for Forest Law Enforcement, Governance and Trade (FLEGT) aimed at reducing the trade and use of illegally harvested timber and to promote the use of legally harvested timber in the European Union (EU). Its underlying rationale is to promote SFM and the rule of law in timber-exporting developing and emerging market countries. The EU proposes to accomplish these goals through Voluntary Partnership Agreements (VPAs) between the EU and timber-producing countries where illegal logging is a problem. The main policy instrument will be the establishment of a licensing scheme to ensure that only timber products that have been produced in accordance with the national legislation of the exporting country are imported into the EU. Once again, the main objective of FLEGT is to reduce deforestation by controlling illegal logging and preventing a 'race to the bottom' where one timber-exporting country can benefit from lax enforcement at the expense of its competitors. As presently constituted, its main contribution to adaptation lies in its efforts to promote SFM and improve governmental capacity. As a sectoral policy initiative, it cannot directly address the pressures from other sectors that will constrain forest adaptation options.

World Bank Forest Strategy 2002

After an extensive evaluation of its previous approach to forests, the Bank adopted a revised Forest Strategy in 2002, locating its interest in forests within the three broad policy 'pillars' of alleviating poverty, promoting sustainable economic development, and conserving the natural environment to protect local and global environmental services. Included in the third pillar are programmes that assist governments to develop measures to mitigate and adapt to the anticipated impacts of climate change and reduce the vulnerability of the poorest people to its effects (World Bank 2004). The 2002 Strategy includes some broad, quantified targets (though none specifically directed at adaptation to climate change), a commitment to monitoring progress, and an analysis of the challenges to successful implementation; this includes the observation that 'the reality is that the flow of funds from donors and multilateral lenders into forests, for management and protection purposes, will continue to be dwarfed by investments in activities that may have damaging impacts on forests' (World Bank 2004, p. 13). The strongest design element in the Strategy is the explicit awareness of the importance of inter-sectoral coordination to prevent sectoral adaptation gains being wiped out by developments in other sectors.

Evaluation and explicit efforts at policy learning are also noteworthy elements in the Bank's approach. The Forest Strategy reviews have provided important feedback about the need for careful policy design, with significant learning about, for example, engaging governments, developing stakeholder capacity and the promise and pitfalls of decentralization initiatives. The Strategy already includes explicit reference to adaptation and adaptation mechanisms. Its fundamental orientation towards conserving forests that provide critical ecological services while promoting SFM in production forests will, if effectively implemented, support national and sub-national efforts to increase the resilience of forests and forest-dependent communities.

Forest Certification

The basic design of forest certification is the promotion of SFM through market incentives. The rationale is the belief that consumers prefer sustainably produced wood products to those which are not sustainably produced and that they are prepared to pay an extra price for them ('green premium'). An independent third party (certifier) assesses the quality of forest management in relation to a set of predetermined standards. The certifier gives a written assurance that the management of a certain forest confirms to the standards (Rametsteiner and Simula

2003). The standards range from relatively loose performance standards (comply with applicable laws) to very detailed prescriptions to be applied at the management-unit level, some of which refer to carbon sequestration.

Forest certification is likely to provide effective market incentives to forest managers if round wood is internationally traded (and not used mainly for domestic consumption), and if these markets are environmentally sensitive. However, increasing amounts of timber are consumed as fuelwood or are destined for markets that are not especially environmentally sensitive. Moreover, certification schemes promote the development of a 'global forestry polity' that transcends the interests of territorial states (Tollefson et al. 2008) and for that very reason they take a sectoral perspective, when adaptation is, above all, an inter-sectoral issue. None the less, certification is a flexible instrument with the possibility that new indicators for forest adaptation measures could be included in the standards of the certification programs.

Main Challenges Facing the International Forest Regime

There are three main design challenges facing the international forest regime. The first is selection of the target groups for optimal results, and the key question here is whether the regime should be aimed primarily at national governments or individual forest projects. The NLBI has clearly chosen the former, the certification movement has chosen projects, while the others fall somewhere in between. With respect to adaptation, there are advantages and disadvantages to each approach. An emphasis at the national level makes it easier to use national C&I to establish goals, monitor progress and develop national capacity to create and enforce regulatory instruments when they are needed. Targeting projects fits with the current emphasis of many ODA agencies on decentralization. For the moment, tracking both targets while we learn which mix of policy instruments works best at each level is desirable. At both levels, it is imperative that policies and programmes address issues of inter-sectoral coordination so that local gains are not wiped out by negative developments in energy, agriculture or macro-economic policies. True policy integration, in which identifying and reducing vulnerabilities and increasing adaptive capacities become explicit goals of land and resource use policies, is best attempted at the national level.

The second design challenge is to provide an appropriate level of financing to achieve the objectives. While a great deal of emphasis is put on the means of implementation, only few financial mechanism has yet been created beyond the existing ones provided by CBD and the United Nations Framework Convention on Climate Change (UNFCCC or FCCC). Therefore, the UN Economic and Social Council decided in December 2007 (December E/2007/277) that UNFF should develop, with a view of adopting it at the eighth session, a financial system for all types of forests. Forest financing can come from domestic and external sources, both public and private. The current external bilateral (official development assistance) and multilateral sources (World Bank, GEF and regional development banks) amount to USD 1.9 billion per year; USD 0.5 billion per year are recorded for foreign private investment. Taking into account other sources of funding on which no consolidated quantitative information is available, the total amount of annual financing flows to forests is many times less than the estimated USD 8.2 billion needed for the sustainable management of the 602 million ha of tropical and subtropical forests (Simula 2008).

The third and most pressing challenge is the construction of a coherent international forest regime that promotes policy learning both within and between its component parts and positive interactions with the other relevant international policy regimes. The success of the UNFF in adopting the four global objectives would go far towards meeting adaptation needs by reducing vulnerabilities. However, the linkages between SFM and climate-change adaptation and positive interactions between the forest regime, the CBD and the UNFCCC, could be facilitated by adding a fifth global objective to the NLBI that specifically refers to climate-change mitigation and adaptation goals. Such an objective would provide guidance and legitimacy for the inclusion of mitigation and adaptation instruments in other components of the forest regime, for example by helping to create the necessary incentives and implementation arrangements at the level of the national forest programmes that are conducive to adaptation. Presently, as we have seen, action at the international level consists of a number of poorly coordinated programmes directed mainly at reducing deforestation rather than addressing the full range of climate-change adaptation issues and options.

7.4.4 The International Climate Change Regime

United Nations Framework Convention on Climate Change and its Kyoto Protocol

The UNFCCC was opened for signatures at the Earth Summit in June 1992 in Rio de Janeiro and entered into force in March 1994. By November 2008 altogether 191 countries and the European Union have become Parties to the Convention. The supreme decision-making body of the UNFCCC is the Conference of Parties (COP). It is supported by two subsidiary bodies; the Subsidiary Body for Scientific and Technical Advice (SBSTA) and the Subsidiary Body for Implementation (SBI).

The goal of the UNFCCC is 'stabilization of greenhouse-gas concentrations in the atmosphere at a level that would prevent dangerous atmospheric interference with the climate system.' Furthermore, 'such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and enable economic development to proceed in a sustainable manner' (Art. 2). The internal target groups of the Convention are the Parties, i.e. states which have ratified the Convention. Parties should take precautionary measures to anticipate, prevent or minimize the causes of climate change and mitigate its adverse effects (Principles, Art. 3.3). The Parties are divided into two main categories: Annex I countries (developed countries) and Non-Annex I countries (developing countries). Among Non-Annex I countries, the Least Developed Countries (LDCs) are often treated as a specific group. These distinctions reflect the recognition of the principle of 'common but differentiated responsibilities and respective capabilities', with the requirement of the developed country Parties taking the lead in combating climate change and the adverse effects thereof. (Art 3.1).

As its title expresses, the UNFCCC is a framework convention, i.e. it defines the aim, principles and instruments in general terms and opens up the possibility of adopting more precise legal instruments, such as the Kyoto Protocol under it (e.g. Art. 17). Nevertheless, the Convention does define a number of important instruments for its implementation. All Parties shall develop and publish national reports: greenhouse-gas inventories to be submitted by Annex I countries annually and national communications to be submitted by both Annex I and Non-Annex I countries periodically (cf. Chapter 5). They shall also formulate and implement national programmes to mitigate climate change and to facilitate adaptation to it.

The Kyoto Protocol entered into force in 2005, and by November 2008 it had been ratified by 182 countries and the European Union. Already in 2001 agreement on the underlying operational rules of the Protocol ('Bonn Agreement') was translated into legal texts, the 'Marrakesh Accords' (COP-7). The Protocol does not include any article on its specific objective but states in its preamble that it has been agreed 'in pursuit of the ultimate objective of the Convention as stated in its Article 2'. The main instruments of the Protocol are legally binding quantified emission limitation and reduction commitments by Annex I countries. The overall Annex I emissions should be at least 5% below their 1990 levels in the first commitment period, 2008 to 2012. Six greenhouse gases are taken into account: carbon dioxide, methane, nitrous oxide and three fluorinated gases.

Annex I Parties are expected to meet their commitments mainly through domestic efforts, but they are allowed to 'supplement' these efforts through the so-called 'flexibility mechanisms': joint implementation (JI, Art 6), clean development mechanism (CDM, Art 12) and emissions trading (ET, Art 17). Through the JI, emissions reduction units resulting from joint projects can be transferred from one Annex I Party to another. CDM provides a similar opportunity for transfers of credits to Annex I countries from projects implemented in developing countries. ET is about trading of credits between Annex I countries. The purpose of the flexibility mechanisms is to increase the cost-efficiency of mitigation activities but also to promote technology transfer and sustainable development in general. As an internal measure, the European Union has established in 2005 its own Emissions Trading System (ETS) among the Member States.

Informal discussions on the further development of the climate-change regime were gradually gaining ground towards the mid-2000s. In 2005 an ad hoc working group was established under the Kyoto Protocol to consider commitments of Annex I countries after 2012. This group has also assessed the existing Kyoto instruments and the need to develop them further. Through the Bali Action Plan adopted in 2007 by COP13 (decision 1/CP.13), this process was complemented with the Ad Hoc Working Group on Long-term Cooperative Action under the Convention that was established for the process 'to enable the full, effective and sustained implementation of the Convention …up and beyond 2012…'. The Bali Action Plan covers the actions by all other countries and addresses five main areas of work, of which the following three are most relevant for forests (see below): (i) enhanced international action on policy approaches and positive incentives on issues related to forests; (ii) enhanced action on adaptation; and (iii) enhanced action on the provision of financial resources and investment to support action on mitigation and adaptation and technology cooperation. Negotiations on these issues are continuing, and it is too early to predict their outcome and the extent to which and how the work of the above-mentioned two ad hoc groups will be packaged.

Forests in the Climate Change Regime

The Convention and its Protocol both treat forests recognizing them as an essential part of the carbon cycle.

Mitigation

'Mitigation' in the climate-change regime refers to the regulation of GHGs in the atmosphere. Forests contribute to mitigation by three avenues: (i) reducing emissions by avoiding deforestation and forest degradation; (ii) protecting the existing forests; and (iii) increasing the sink effect of forests by land use, land-use change and forestry activities (LULUCF). As mitigation regarding LULUCF is beyond the scope of this paper, protection of existing forests and, simultaneously, reducing emissions from deforestation and forest degradation is a key concern of climate change and forest policy and will be dealt with separately below.

In the Kyoto Protocol, protection and enhancement of forests, promotion of sustainable forest management practices and afforestation and reforestation are listed among possible policies and measures for achieving Annex I emission limitation and reduction commitments (Arts. 2.1). Annex I countries also have an obligation to account for the outcome of afforestation, reforestation and deforestation activities when reporting about the achievement of their commitments (Art 3.3). Furthermore, Annex I countries can on a voluntary basis include in the national accounting system additional human-induced activities that have taken place since 1990, including effects of forest management (Art 3.4). Finally, afforestation and reforestation (AR) are eligible activities within the CDM. However, the rules for these CDM projects (19/CP.9) are constraining and complicated; for the time being, CDM has endorsed only one forest project (Simula 2008).

Adaptation

Even if GHG emissions are reduced urgently and drastically, climate change will continue due to past emissions and the inertia of the climate system. Therefore, forests and people have to adapt to the adverse effects. Concern about adaptation is expressed already in the ultimate objective of the Convention (Art 2). In the operative articles, all Parties commit themselves to prepare adaptation programmes and to cooperate in preparing for adaptation to impacts of climate change (Art 4.1). The developed countries shall assist the developing countries that are particularly vulnerable in meeting costs of adaptation (Art. 4.4). All Parties shall give full consideration to what actions are necessary to meet the specific needs and concerns of developing countries arising from adverse effects of climate change (Art 4.8). National communications to be prepared by all Parties shall provide descriptions of steps taken or envisaged by Parties, including those for adaptation (Art 12). The Marrakesh Accords introduced support to National Adaptation Programmes of Action (NAPAs) of least developed countries to build their capacities (cf. subchapter 7.3.1).

Another important development within the UNFCCC is the Nairobi Work Programme, aimed at assisting countries to improve their understanding of impacts, vulnerability and adaptation. The programme modalities include information exchange, expert meetings, workshops and reports. A great deal of attention is paid to engaging a wide range of organizations, institutions, experts and communities (FCCC/SBSTA/2006/11). A concrete outcome of the programme is the compilation of methodologies and tools to assess vulnerability and adaptation strategies, including forests, particularly in developing countries (Robledo et al. 2008).

In the Bali Action Plan, enhanced adaptation action is one of the key areas of work. The following issues are considered: international cooperation to support implementation of adaptation activities; risk management and risk-reduction strategies; disaster-reduction strategies; economic diversification; and ways to strengthen the catalytic role of the convention in encouraging multilateral bodies and public and private sectors to build on synergies among activities and processes, as a means of supporting adaptation in a coherent and integrated manner. All these areas are relevant for multilateral bodies working in the field of forestry, and indeed the last point stresses the role of other actors and the need for cooperation.

Reducing Emissions from Deforestation and Forest Degradation (REDD)

About one fifth of global emissions of carbon dioxide are estimated to originate from tropical deforestation (Houghton 2005), and reducing deforestation would thus greatly contribute to mitigation efforts. However, in the Marrakesh Accords, avoided deforestation was explicitly not included in the CDM due to methodological and political hurdles which could not be overcome. In the negotiations leading to the Marrakesh Accords, there were widespread concerns of the risks related to the permanence, leakage and verifiability of credits earned through forest-related activities. Permanence is related to loss of carbon sequestered by forests though tree felling, forest fires, etc. Leakage means the displacement of deforestation from the region credited for avoiding deforestation to another region. Verifiability is related to the possibility of ensuring the credibility of the forest-related carbon credits. A thorny issue related to all CDM projects is their additionality, i.e. ensuring that resulting CDM credits reflect an improved situation beyond the business-as-usual development, including beyond the implementation of existing legislation and policies. This is also a methodological challenge: e.g. if avoided deforestation became an eligible CDM activity, what method would be used to set the baseline for a country's deforestation reduction? These concerns were especially strong regarding activities under the CDM, since developing countries are not subject to the same monitoring system as the Annex I countries with legally binding commitments.

The Bali Action Plan includes consideration of policy approaches and positive incentives to reduce emissions from deforestation and forest degradation (REDD) in developing countries and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries. Attention is also paid to finding ways to strengthen the catalytic role of the Convention in encouraging multilateral bodies of public and private sectors, building on synergies among activities and processes (1/CP13). In this context REDD may benefit from research into the causes of deforestation (Kanninen et al. 2007).

A key policy instrument of REDD is financial incentives for these countries which are prepared to reduce deforestation and forest degradation in the future. Two basic options have frequently been brought up for raising money: a market-based approach and a fund-based approach. The market-based approach can be a modified regulatory carbon market under the Kyoto Protocol and, in addition, a voluntary carbon market which already exists (Portela et al. 2008). In addition to credits for avoided deforestation, forestry projects can also include payments for environmental services (PES), such as provision of biodiversity, soil and watershed protection, and SFM at a project and at a broad landscape level (Meizlish and Brand 2008). An example of the fund-based approach to REDD is the Forest Carbon Partnership Facility (FCPF) established by the World Bank in 2006. It is designed to examine the preconditions for the successful formulation and implementation of REDD and to assist developing countries in their efforts to reduce emissions. Under the FCPF there are two funding sources: the Readiness Fund covers preparatory measures for target countries, such as assessing historical emissions from deforestation and forest degradation, setting baselines; and the Carbon Fund which will contribute to emission reductions based on sound approaches (Simula 2008).

Funding Arrangements within the Climate Regime

Within the climate-change regime, there are now several funding arrangements in support of adaptation and mitigation activities, including those related to forests. The Global Environmental Facility (GEF) has been entrusted with the operation of the financial mechanism of the UNFCCC. The GEF provides funding for the preparation of Non-Annex I countries' national communications and can cover incremental costs of projects with global climate benefits. It also supports capacity-building and demonstration projects related to adaptation. Under GEF, there has been a Strategic Priority on Adaptation (SPA) Trust Fund.

In the Marrakesh Accords two funds were created under the UNFCCC: the Special Climate Change Fund (SCCF) and the Least Developed Countries Fund (LDCF). A third fund was established under the Kyoto Protocol, the Adaptation Fund (AF) (Decisions 10/CP. 7). While the operation of the two funds under the Convention has been assigned to the GEF, the Adaptation Fund is administered by a separate Adaptation Fund Board, for which the GEF provides secretariat services.

The Special Climate Change Fund (SCCF) was established to finance projects in Non-Annex I countries relating to adaptation, technology transfer, energy, transport, industry, agriculture, forestry and waste management, and economic diversification. The Least Developed Countries Fund (LDCF) has so far supported the preparation of National Adaptation Plans of Action (NAPAs) in 48 least developing countries. The Adaptation Fund (AF) can finance concrete adaptation projects and thus help developing countries cope with the effects of climate change. The AF is considered an interesting example of innovative funding: the main source of its funds is a 2% levy on projects from CDM. The Trust Fund Strategic Priority on Adaptation (SPA) is aimed at showing how adaptation planning and assessment can be translated into practical projects that provide real benefits.

In concurrence with the Bali Action Plan, the World Bank created the Climate Investment Funds (CIFs) in July 2008. They consist of the following two distinct trust funds: the Clean Technology Fund and the Strategic Climate Fund. The CIFs are a collaborative effort among the Multilateral Development Banks and countries to bridge the financing and learning gap between now and post-2012 global climate-change agreement. They should be in addition to existing Official Development Assistance (ODA) and operated in close coordination with the GEF and the Adaptation Fund under the Kyoto Protocol. The Clean Technology Fund will accelerate cost-effective mitigation of GHG emissions in developing countries by demonstration, deployment and transfer of low-carbon technologies. The Strategic Climate Fund will help more vulnerable countries adapt their development programmes to the impacts of climate change and will take action to prevent deforestation. It will explore political ways to integrate climate resilience into core development planning and budgeting, building on NAPAs. Furthermore, it will strategically align with the Adaptation Fund.

Main Challenges Facing the International Climate Change Regime

From a policy design perspective, there are several major shortcomings of the UNFCCC and its KP regarding adaptation of forests to climate change and avoiding emissions from deforestation and forest degradation.

Regarding adaptation, the first shortcoming is the dominant role played by mitigation goals and the consequent risk that adaptation policies are caught up in CDM. There are strong arguments for separating forest sequestration programmes from emission reduction programmes. The result would be to turn the current emphasis around, focusing on policies that aim to discourage deforestation, to encourage the conversion of marginal agricultural land to forests, and for priority implementation of SFM in countries with high forest cover, all of which would improve adaptive capacity while contributing to mitigation (Plantinga and Richards 2008). Unfortunately, the second shortcoming is the lack of funding, and separating forest programmes from emission allowance programmes will probably make this worse by removing an important potential source of investment (Aldy and Stavins 2008). The current levels of pledges for financing climate-change mitigation and adaptation options through the GEF and GEF-administered funds amount to USD 90 million for the SCCF, USD 180 million for the LDCF and USD 50 million for the SPA. Currently, the AF is worth about EUR 50 million. Considering the number of CDM projects in the pipeline, this figure will rapidly increase to an estimated USD 80–300 million in the period 2008–2012. Yet, these funding resources are insufficient to cover even the costs of adaptation of forests and people to climate change in developing countries, even if they were not needed for anything else. However, as to future developments, the Bali Plan of Action includes consideration of enhanced action on the provision of financial resources and investment to support action on mitigation, adaptation and technology cooperation.

REDD's funding gap is not very different. The opportunity costs of REDD are estimated at USD 12.2 billion per year, considering that the annual deforestation in tropical countries amounts to 12.9 million ha (UNFCCC 2007, quoted by Simula 2008). This amount is not in balance with the current funding sources of regulatory and voluntary carbon markets, governmental initiatives and the Forest Carbon Partnership Facility. Funds to be raised from carbon markets are difficult to estimate. Presently, there are about 20 governmental initiatives to provide funding for tropical forest conservation. The most important ones are the Amazon Fund (launched in August 2008) with an initial target of USD 1 billion per year; the Congo Basin Forest Fund (launched in June 2008) with grants from the British and Norwegian governments of together USD 216 million; Australia's International Forest Carbon Initiative of about USD 186 million. Norway has started to implement a programme with an upper limit of funding of USD 600 million per year. Finally, the target capitalization of the FCPF is at least USD 300 million. Although these figures show the readiness for action and willingness to pay, there is still a huge gap between the needs and actual funding for REDD (Simula 2008).

7.5 Conclusions

7.5.1 General Findings

This assessment of policy and governance options for the adaptation of forests to climate change began by noting the difficulty of carrying out such an assessment given the current state of knowledge about climate-change impacts on the ground. Lacking basic biophysical information about the adaptive capacity of forest ecosystems creates uncertainty about socio-economic vulnerabilities and management options. This, in turn, makes it difficult to generalize about governance capacity, our ability to create the appropriate framework of institutions, and policies that will promote adaptation to climate change. None the less, it is clear that climate change raises two general challenges at which policy and governance will be directed.

The first problem is to integrate adaptation to climate change into SFM. As a result of the various SFM dialogues that have taken place over the last decade, considerable progress has already been made on agreement about the goals, but the means remain contested. At the management-unit level, everything depends on the forest site (see confirmation of Wilhelm Pfeil's 'iron law of the site' in Chapter 6). The solution needs 'consensus-building' (Lee 1993) among all forest stakeholders. Once agreement on goals becomes more widespread, for example as the result of a NFP, the question of appropriate means can more easily be dealt with. Forest managers who are familiar with the relevant causal factors affecting forest health will play a larger role, guided by outcomes-based performance standards. As Lee states, this strategy benefits from major changes introduced from outside, so that new issues and new alignments of parties and interests can supplant existing lines of division. Adaptation of forests to climate change is such a driving force from outside, with significant potential to create a realignment of interests. According to this strategy we have proposed a number of policy tools to address adaptation.

The second problem is that climate change cre-

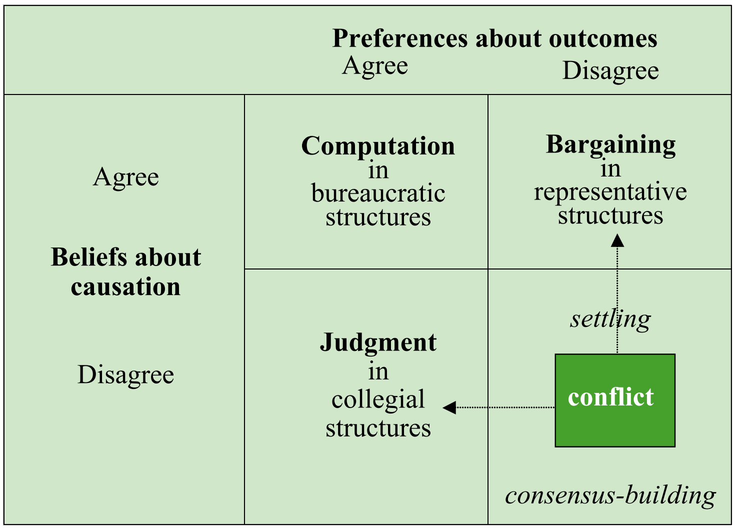

Figure 7.2 Social decision-making under varying conditions of agreement (Lee 1993, p. 106).

ates new pressures for increased deforestation and forest degradation, both as an attempt to compensate for lost agricultural productivity from drought or diseases and for growing biofuel crops to replace fossil fuels. The severity of the problem is compounded by the weakness of the international forest regime and its current lack of effectiveness in combating existing drivers of deforestation: 'deforestation is a symptom of a multi-causal disease for which a proven cure does not yet exist' (Streck et al. 2008, p. 247). Thus, efforts must be directed towards obtaining agreement on the causes of deforestation, which is more difficult when climate-change drivers are added to the existing mix of causes. As Lee (1993, p. 108) argues, 'this strategy launches a process of bargaining and negotiation, usually by representatives of larger groups or interests.' He calls this intervention method 'settling', 'since the aim of the negotiation is not to achieve final resolution of conflict, but rather to hammer out joint actions within a relationship in which all parties are aware of and retain opposed interests' (Lee 1993). In that case, collaboration of the participants has often to be forced from outside by government or international donor organizations. Agreements in such negotiations can be facilitated by the pressure from deadlines or from threats to cut funding. The ongoing negotiations on REDD are an example of settling in Lee's sense.

The solution of both problems can be illustrated by Figure 7.2. It represents a typology of social decision processes depending on agreement or disagreement over goals (preferences about outcomes) and agreement or disagreement over means (beliefs about causation).

7.5.2 Specific Findings

Consensus Building

The appropriate policy instruments here are procedural and stress multi-stakeholder collaborative processes. The process of consensus-building will typically take place in these large-scale stakeholder consultations, for example in NFPs and NASs (National Adaptation Strategies), which must be strengthened. Thus, building capacity to conduct these exercises, especially in countries without a strong consultative tradition (which includes many developed countries), must be a priority. The C&I for SFM should be modified to include criteria for vulnerability and adaptive capacity. The NLBI should retain the promotion of NFPs in its strategic objectives, while adding a fifth objective that makes explicit reference to climate-change adaptation.

While consensus-building is taking place, the central message about the choice of policy instruments is to encourage experimentation and provide maximum flexibility for local innovation. For this reason, traditional policy mixes that combine regulation and subsidies are unattractive. The ability to produce efficient and reasonable outcomes in the face of what is expected to be changing (perhaps rapidly changing) conditions requires flexible policy instruments. In particular, given the need to encourage and reward successful innovation and technical progress in forest management, market-based instruments are preferred. SFM standards should be developed in the direction of performance or outcome standards rather than prescription. Voluntary agreements, labelling and other means of providing information can be used to address the complexities and uncertainties of the ecological issues at stake. Promoting adaptive practices through certification is promising in this respect, although, as noted above, only when forest products are traded into markets that are sensitive to environmental concerns.

On forest governance to promote consensus building, it has been have emphasized throughout the chapter that, although adaptive policy needs a forest focus, it cannot ignore the many drivers of change that originate in other sectors. Forest governance must continue to work towards better inter-sectoral coordination as a first step towards an integrated approach to land use and land management. Unrelated developments in agriculture, energy, transportation, conservation and even macroeconomic policies can have dramatic effects on the incentives to destroy or degrade forests. There are no easy answers here. Studies continue to show that policy integration is usually hampered by profound policy legacies, including the familiar administrative 'silos' that result in distinct land uses having their own planning, permitting and monitoring regimes with their own powerful client groups and political champions. Again, policy-makers need to seize opportunities to demonstrate the benefits of tackling adaptation through integrated land use at the project level rather than attempting large-scale transformative changes that almost always fail (Lim at al. 2004).

Settling

The creation of joint actions in which participants set aside their differences about goals and priorities to search for effective policy means starts with broad agreement on at least two policy tools: portfolio financing and research. With respect to financing, there is a substantial shortfall in both the amounts and the precise targeting of funding necessary to reduce deforestation to the levels required. For this reason, 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 programmes for meeting the projected funding shortfall for adaptation, while simultaneously seeking to restore ODA funding for SFM under the NLBI. As the evaluations of the World Bank Forest Strategy clearly showed, financial incentives are very effective policy levers, and it is better to learn pragmatically how to improve their precision as we go along rather than refraining from using them at all until they are refined to everyone's satisfaction.

Another critical subcategory of programmes involves research. There will be less need for 'settling' and more opportunities for consensus-building once the scope, scale and direction of climate-change impacts are more clearly understood and vulnerability assessments can be produced at regional and local scales. Assessments that can clearly distinguish the background adaptive capacities of ecosystems from vulnerabilities caused by social impacts and weak governance capacities should be a priority. Once these assessments can be carried out, the necessary scale of the interventions needed to address social impacts and strengthen governance capacities will become clearer and it will be possible to move on to prioritizing goals.

In the meantime, especially at the level of specific policy instruments, it is inevitable that these programmes will continue to experiment with a broad range of tools that are intended to compensate local economies for the global benefits that they are providing and to transfer best practices. These experiments must be encouraged and allowed to continue. When coupled with better monitoring and evaluation, a variety of programmes is highly desirable as a means of promoting policy learning and improving the rewards of joint action. However, the same variety demands greatly improved coordination between these regimes to ensure that adaptation is pursued hand in hand with climate-change mitigation, human security, biodiversity conservation and many other equally desirable global goals whose relative priority is a major source of disagreement.

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8 Main Conclusions and the Way Forward

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Forests provide essential services to support human well-being. They cover about a third of the Earth's land surface, grow in many climates, store about half the total carbon contained in land ecosystems and, very likely, host the majority of terrestrial biodiversity. The impacts of future climate change on forest ecosystems and the goods and services they provide are therefore of major global concern.

Regardless of mitigation measures taken now or in the near future, historical emissions and inertia in the climate system mean that some climate change has become inevitable. Individuals, societies and institutions, therefore, should be aware of those likely and possible future impacts of climate change on forests and have management and policy options at hand to support adaptation.

The assessment of available scientific information in this report confirms that climate change is already affecting forest ecosystems and the services they provide, and will have increasing effects on them in the future. The ongoing climate change could put at risk essential ecosystem services, including carbon regulation and the maintenance of biodiversity; the loss of carbon-regulating services would seriously accelerate climate change.

The negative social and economic consequences of a loss of forest ecosystem services due to climate change are potentially dramatic. The forest-dependent poor in particular will, in many regions, face increasing difficulty in meeting basic needs for energy, food and clean water, which would lead to deepening poverty, deteriorating public health and increasing social conflicts. In many countries, current governance failures increase the socio-economic vulnerability of many people.

Climate change could have positive effects as well. The increases in economic productivity that will occur in forests in some regions due to increased tree growth will present new opportunities for forest industry and forest-dependent communities.

This assessment has revealed the limitations in current knowledge on the impacts of climate change on forests and people. Forest adaptation studies are relatively recent, and only a few have documented evidence of success in the implementation of adaptation strategies. It is necessary, therefore, to continue to support research that will reduce uncertainty about the local level climate-change impacts on forests and improve knowledge about management and policy measures that will promote successful adaptation. The well-planned monitoring and evaluation of adaptation measures is important to facilitate continuous learning and to enable the further development of such measures.

Existing climate-change scenarios and ecological models should be further developed to adequately explore the complex interactions between forests and the climate system. Given the diversity of forests, more precise regional and local climate-change projections are urgently required. Much more research is also needed on the forest-related social and economic impacts of climate change, especially on forest-dependent people. Projections of future economic conditions are inherently uncertain, not least because they are linked to climate and ecological models that contain their own uncertainties. The current lack of data on the supply of many non-wood forest products and their future demand imposes further limits on the assessment of climate-change impacts.

Climate change is only one factor affecting forests and the people depending on them for their livelihoods. Others include human population growth, changes in the extent of croplands and pasturelands, epidemic diseases, invasive species, forest fire and industrial pollution. The effects of such factors, and their interactions with climate change, complicate analyses of the impacts of climate change on forest goods and services.

Despite the limitations of current knowledge, climate change is progressing too quickly to postpone action pending the outcomes of future studies. This assessment has revealed strategies that can significantly reduce climate change risks and enhance the adaptation of forests and people to climate change. It confirms that the practices associated with sustainable forest management are likely to help reduce environmental, social and economic vulnerabilities under a wide range of potential future climatic conditions. Therefore, better implementation of sustainable forest management can immediately help to reduce vulnerability to climate change. Actions aimed at maintaining and increasing the diversity of species and genes in forests can help mitigate climate change risks. Many management actions taken in the context of adaptation, such as the prevention of large-scale fires, could also assist in the mitigation of climate change. By and large, forest managers will need sufficient flexibility to choose locally appropriate adaptation measures.

New modes of governance are required that enable meaningful stakeholder participation and provide secure land tenure and forest user rights and sufficient financial incentives. Flexible approaches to policy design are needed that are sensitive to context and do not rely on a single, one-size-fits-all mechanism. 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.

Climate change adaptation and mitigation are closely linked and complementary. Indeed, given the importance of forests to climate, successful mitigation requires that forests are able to adapt to climate change. This suggests opportunities to at least partly finance adaptation costs through payments for mitigation services.

Unmitigated climate change is likely to exceed the adaptive capacity of many forests in the course of the current century. On their own, therefore, adaptation measures will be insufficient for forests to adapt to climate change; large reductions in emissions from fossil fuels and deforestation are needed to preserve the adaptive capacity of forests and to enable them to continue making their essential contribution to the mitigation of climate change.

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Glossary

The selection of the terms and their definitions has been done in cooperation with the authors of this report. The definitions describe the key terms and the meaning in which they have been used in this report. The glossary builds on internationally agreed concepts, terms and definitions. Most of the given definitions are agreed by the Intergovernmental Panel on Climate Change (IPCC) and/or the Food and Agriculture Organization of the United Nations (FAO). Other definitions have been used where no IPCC or FAO definitions exist or where other definitions better convey the understanding of the term in this report. A reference is provided for each term and definition.

ADAPTATION

Adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities.

- Anticipatory adaptation: Adaptation that takes place before impacts of climate change are observed.
- Autonomous adaptation: Adaptation that does not constitute a conscious response to climate stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems. Also referred to as spontaneous adaptation.
- Planned adaptation: Adaptation that is the result of a deliberate policy decision, based on an awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve the desired state (IPCC 2007a).

ADAPTIVE CAPACITY (in relation to climate change impacts)

The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC 2007a).

ADAPTIVE MANAGEMENT

A dynamic approach to forest management in which the effects of treatments and decisions are continually monitored and used, along with research results, to modify management on a continuing basis to ensure that objectives are being met (IUFRO 2005).

AEROSOLS

A collection of air-borne solid or liquid particles, with a typical size between 0.01 and 10 μm, that reside in the atmosphere for at least several hours. Aerosols may be of either natural or anthropogenic origin. Aerosols may influence climate in two ways: directly through scattering and absorbing radiation, and indirectly through acting as condensation nuclei for cloud formation or modifying the optical properties and lifetime of clouds (IPCC 2007a).

AFFORESTATION

Establishment of forest plantations on land that, until then, was not classified as forest. Implies a transformation from non-forest to forest (FAO 2001a).

AGROFORESTRY

Practices of growing trees with agricultural crops and/or animals, in interacting combinations as well as the interdisciplinary subject area embracing land use system, form field to global level, that involve deliberate retention, introduction, or mixture of trees in crop and animal production systems to take advantage of economic or ecological interactions among the components (IUFRO 2005).

ALIEN SPECIES

(non-native, non-indigenous, foreign, exotic) means a species, subspecies, or lower taxon occurring outside of its natural range (past or present) and dispersal potential (i.e. outside the range it occupies naturally or could not occupy without direct or indirect introduction or care by humans) and includes any part, gametes or propagule of such species that might survive and subsequently reproduce (IUCN 2000).

BIODIVERSITY

The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (CBD 1992).

BIOFUEL

A fuel produced from organic matter or combustible oils produced by plants. Examples of biofuels include alcohol, black liquor from the paper-manufacturing process, wood and soybean oil (IPCC 2007a**).**

BIOMASS

Organic material both above-ground and below-ground, and both living and dead, e.g. trees, crops, grasses, tree litter, roots, etc. Biomass includes the pool definition for above- and below-ground biomass. Above-ground biomass: all living biomass above the soil including stem, stump, branches, bark, seeds and foliage. Below-ground biomass: all living biomass of live roots. Fine roots of less than (suggested) 2mm diameter are sometimes excluded because these often cannot be distinguished empirically from soil organic matter or litter (FAO 2004).

BIOME

Major and distinct regional element of the biosphere, typically consisting of several ecosystems (e.g. forests, rivers, ponds, swamps) within a region of similar climate. Biomes are characterised by typical communities of plants and animals (IPCC 2007a).

BOREAL FOREST DOMAIN

The boreal domain is found only in the higher latitudes of the Northern Hemisphere between 50–55 and 65–70 degrees. It has at least one and up to 4 months with an average temperature above 10°C. Another feature is the large annual range of temperature. Rainfall is low, generally below 500mm (FAO 2001b). See Chapter 3 for more detailed description.

CAPACITY BUILDING

In the context of climate change, capacity building is developing the technical skills and institutional capabilities in developing countries and economies in transition to enable their participation in all aspects of adaptation to, mitigation of, and research on climate change, and in the implementation of the Kyoto Mechanisms, etc.
(IPCC 2007a)

CARBON SEQUESTRATION

The process of increasing the carbon content of a reservoir/pool other than the atmosphere
(IPCC 2007a).

CARBON SINK

Any process, activity or mechanism that removes a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol from the atmosphere.
(IPCC 2007a)

CARBON SOURCE

Any process, activity, or mechanism that releases a greenhouse gas, an aerosol, or a precursor of a greenhouse gas or aerosol into the atmosphere (IPCC 2001).

CARBON STOCK/RESERVOIR

A component of the climate system, other than the atmosphere, that has the capacity to store, accumulate or release a substance of concern (e.g. carbon or a greenhouse gas). Oceans, soils, and forests are examples of carbon reservoirs (IPCC 2007a).

CLIMATE

Climate in a narrow sense is usually defined as the 'average weather', or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. These quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. The classical period of time is 30 years, as defined by the World Meteorological Organization (IPCC 2007a).

CLIMATE CHANGE

Climate change refers to any change in climate over time, whether due to natural variability or as a result of human activity. This usage differs from that in the United Nations Framework Convention on Climate Change (UNFCCC), which defines 'climate change' as: "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods" (IPCC 2007a). See also climate variability.

CLIMATE CHANGE IMPACT, ADAPTATION AND VULNERABILITY (CCIAV) ASSESSMENT

In the context of climate change the assessment of impacts, adaptation (see adaptation) and resulting vulnerability (see vulnerability) for a specific natural or anthropogenic system, sector, or region. Depending on circumstances (goals, scope, methodology) there are several approaches for CCIAV (IPCC 2007b).

CLIMATE MODEL

A numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes, and accounting for all or some of its known properties. The climate system can be represented by models of varying complexity (i.e., for any one component or combination of components a hierarchy of models can be identified, differing in such aspects as the number of spatial dimensions, the extent to which physical, chemical, or biological processes are explicitly represented, or the level at which empirical parameterisations are involved. Coupled atmosphere/ ocean/sea-ice General Circulation Models (AOGCMs) provide a comprehensive representation of the climate system. More complex models include active chemistry and biology. Climate models are applied, as a research tool, to study and simulate the climate, but also for operational purposes, including monthly, seasonal and inter-annual climate predictions (IPCC 2007a).

CLIMATE (CHANGE) SCENARIOS

A plausible and often simplified representation of the future climate, based on an internally consistent set of climatological relationships and assumptions of radiative forcing, typically constructed for explicit use as input to climate change impact models. A 'climate change scenario' is the difference between a climate scenario and the current climate (IPCC 2007a).

CLIMATE SENSITIVITY

The equilibrium temperature rise that would occur for a doubling of CO_2 concentration above pre-industrial levels (IPCC 2007a).

CLIMATE VARIABILITY

Climate variability refers to variations in the mean state and other statistics (such as standard deviations, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability) (IPCC 2007a). See also climate change.

CONFIDENCE

See uncertainty.

DEFORESTATION

The conversion of forest to another land use or the long-term reduction of the tree canopy cover below the minimum 10% threshold.

Explanatory notes:

- Deforestation implies the long-term or permanent loss of forest cover and implies transformation into another land use. Such a loss can only be caused and maintained by a continued human-induced or natural perturbation.

- Deforestation includes areas of forest converted to agriculture, pasture, water reservoirs and urban areas.
- The term specifically excludes areas where the trees have been removed as a result of harvesting or logging, and where the forest is expected to regenerate naturally or with the aid of silvicultural measures. Unless logging is followed by the clearing of the remaining logged-over forest for the introduction of alternative land uses, or the maintenance of the clearings through continued disturbance, forests commonly regenerate, although often to a different, secondary condition. In areas of shifting agriculture, forest, forest fallow and agricultural lands appear in a dynamic pattern where deforestation and the return of forest occur frequently in small patches. To simplify reporting of such areas, the net change over a larger area is typically used.
- Deforestation also includes areas where, for example, the impact of disturbance, overutilisation or changing environmental conditions affects the forest to an extent that it cannot sustain a tree cover above the 10% threshold (FAO 2001a).

DESERTIFICATION

Desertification means land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities.

Land degradation means reduction or loss in arid, semi-arid and dry sub-humid areas of the biological or economic productivity and complexity of rainfed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as: (i) soil erosion caused by wind and/or water; (ii) deterioration of the physical, chemical and biological or economic properties of soil; and (iii) long-term loss of natural vegetation (UN 1994).

DOMAIN

Broadest entity or level in classification, equivalent to the five thermic Köppen – Trewartha climatic groups and including the tropical, subtropical, temperate, boreal and polar domain (FAO 2001b).

DYNAMIC GLOBAL VEGETATION MODEL (DGVM)

Models that simulate vegetation development and dynamics through space and time, as driven by climate and other environmental changes (IPCC 2007a).

ECOSYSTEM SERVICES

Ecological processes or functions having monetary or non-monetary value to individuals or society at large. There are (i) supporting services such as productivity or biodiversity maintenance, (ii) provisioning services such as food, fibre or fish, (iii) regulating services such as climate regulation or carbon sequestration, and (iv) cultural services such as tourism or spiritual and aesthetic appreciation (IPCC 2007a).

EL NIÑO-SOUTHERN OSCILLATION (ENSO)

El Niño, in its original sense, is a warm-water current that periodically flows along the coast of Ecuador and Peru, disrupting the local fishery. This oceanic event is associated with a fluctuation of the inter-tropical surface pressure pattern and circulation in the Indian and Pacific Oceans, called the Southern Oscillation. This coupled atmosphere-ocean phenomenon is collectively known as El Niño-Southern Oscillation. During an El Niño event, the prevailing trade winds weaken and the equatorial counter current strengthens, causing warm surface waters in the Indonesian area to flow eastward to overlie the cold waters of the Peru current. This event has great impact on the wind, sea surface temperature, and precipitation precipitation patterns in the tropical Pacific. It has climatic effects throughout the Pacific region and in many other parts of the world. The opposite of an El Niño event is called La Niña (IPCC 2007a).

EMISSIONS SCENARIO

A plausible representation of the future development of emissions of substances that are potentially radiatively active (e.g. greenhouse gases, aerosols), based on a coherent and internally consistent set of assumptions about driving forces (such as demographic and socio-economic development, technological change) and their key relationships. In 1992, the IPCC presented a set of emissions scenarios that were used as a basis for the climate projections in the Second Assessment Report. These emissions scenarios are referred to as the IS92 scenarios. In the IPCC Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000), new emissions scenarios – the so-called SRES scenarios – were published (IPCC 2007a).

EXTREME WEATHER EVENT

An event that is rare within its statistical reference distribution at a particular place. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as or rarer than the 10th or 90th percentile. By definition, the characteristics of what is called 'extreme weather' may vary from place to place. Extreme weather events may typically include floods and droughts (IPCC 2007a).

FOREST

Land spanning more than 0.5ha with trees higher than 5m and a canopy cover of more than 10%, or trees able to reach these thresholds in situ. It does not include land that is predominantly under agricultural or urban land use.

Explanatory notes

- Forest is determined both by the presence of trees and the absence of other predominant land uses. The trees should be able to reach a minimum height of 5m in situ. Areas under reforestation that have not yet reached but are expected to reach a canopy cover of 10% and a tree height of 5m are included, as are temporarily unstocked areas, resulting from human intervention or natural causes, which are expected to regenerate.
- Includes areas with bamboo and palms provided that height and canopy cover criteria are met.
- Includes forest roads, firebreaks and other small open areas; forest in national parks, nature reserves and other protected areas such as those of specific scientific, historical, cultural or spiritual interest.
- Includes windbreaks, shelterbelts and corridors of trees with an area of more than 0.5 ha and width of more than 20m.
- Includes plantations primarily used for forestry or protection purposes, such as rubber wood plantations and cork oak stands.
- Excludes tree stands in agricultural production systems, for example in fruit plantations and agroforestry systems. The term also excludes trees in urban parks and gardens (FAO 2004).

FOREST DEGRADATION

Changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services (FAO 2001a).

FOREST DEPENDENT PEOPLE

Encompasses people and communities that have a direct relationship with forests and trees and live within or immediately adjacent to forested areas, and depend on them for their sustenance (FAO 1996).

FOREST ECOSYSTEM

An ecological system composed of interacting biotic and abiotic components of the environment, in witch trees are major constituent (IUFRO 2005).

FOREST MANAGEMENT

The processes of planning and implementing practices for the stewardship and use of forests and other wooded land aimed at achieving specific environmental, economic, social and/or cultural objectives. Includes management at all scales such as normative, strategic, tactical and operational level management (FAO 2004).

FOREST PLANTATION

Forest stands established by planting or/and seeding in the process of afforestation or reforestation. They are either of introduced species (all planted stands), or intensively managed stands of indigenous species, which meet all the following criteria: one or two species at plantation, even age class, regular spacing (FAO 2004).

FOREST REHABILITATION

The process of restoring the capacity of a forest to provide goods and services again, where the state of the rehabilitated forest in not identical to its state before (CPF 2005).

FOREST RESOURCE

For the purposes of the global forest resources assessments, forest resources include those found in forests and other wooded land and as trees outside forests (FAO 2004).

FOREST RESTORATION

The process of restoring a forest to its original state before degradation (same functions, same structure, same composition) (CPF 2005).

GOVERNANCE

Refers to the rules, institutions and systems of the state operating at international, national and local levels. It also refers to how the state interacts with citizens, private businesses and civil society organisations (IUFRO 2005).

GREENHOUSE GAS

Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. As well as CO_2, N_2O, and CH_4, the Kyoto Protocol deals with the greenhouse gases sulphur hexafluoride (SF^6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs) (IPCC 2007a).

HUMAN SYSTEM

Any system in which human organisations play a major role. Often, but not always, the term is synonymous with 'society' or 'social system' e.g. agricultural system, political system, technological system and economic system are all human systems (IPCC 2007a).

IMPACTS

The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts:

- Potential impacts: all impacts that may occur given a projected change in climate, without considering adaptation.
- Residual impacts: the impacts of climate change that would occur after adaptation. (IPCC 2007a).

INDIGENOUS KNOWLEDGE

See local knowledge.

INDIGENOUS PEOPLES

No internationally accepted definition of indigenous peoples exists. Common characteristics often applied under international law, and by United Nations agencies to distinguish indigenous peoples include: residence within or attachment to geographically distinct traditional habitats, ancestral territories, and their natural resources; maintenance of cultural and social identities, and social, economic, cultural and political institutions separate from mainstream or dominant societies and cultures; descent from population groups present in a given area, most frequently before modern states or territories were created and current borders defined; and self-identification as being part of a distinct indigenous cultural group, and the desire to preserve that cultural identity (IPCC 2007a).

INVASIVE ALIEN SPECIES

Any species that are non-native to a particular ecosystem and whose introduction and spread causes, or are likely to cause, socio-cultural, economic or environmental harm or harm to human health (FAO 2008a).

INVASIVE SPECIES

Organisms (usually transported by humans) which successfully establish themselves in, and then overcome pre-existing native ecosystems (IUFRO 2005).

KYOTO PROTOCOL

The Kyoto Protocol was adopted at the Third Session of the Conference of the Parties (COP) to the UN Framework Convention on Climate Change (UNFCCC) in 1997 in Kyoto, Japan. It contains legally binding commitments, in addition to those included in the UNFCCC. Countries included in Annex B of the Protocol (most member countries of the Organisation for Economic Cooperation and Development (OECD) and those with economies in transition) agreed to reduce their anthropogenic greenhouse gas emissions (CO_2, CH_4, N_2O, HFCs, PFCs, and SF_6) by at least 5% below 1990 levels in the commitment period 2008 to 2012. The Kyoto Protocol entered into force on 16 February 2005 (IPCC 2007a).

LIVELIHOOD

Livelihoods consist of the capabilities, assets – both material and social resources – and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks, maintain or enhance its capabilities and assets, and provide net benefits to other livelihoods locally and more widely, both now and in the future, while not undermining the natural resource base (FAO 2008b).

LOCAL KNOWLEDGE, INDIGENOUS KNOWLEDGE

Indigenous Knowledge (IK) can be broadly defined as the knowledge that an indigenous (local) community accumulates over generations of living in a particular environment. This definition encompasses all forms of knowledge – technologies, know-how skills, practices and beliefs – that enable the community to achieve stable livelihoods in their environment. A number of terms are used interchangeably to refer to the concept of IK, including Traditional Knowledge (TK), Indigenous Technical Knowledge (ITK), Local Knowledge (LK) and Indigenous Knowledge System (IKS). IK is unique to every culture and society and it is embedded in community practices, institutions, relationships and rituals. IK is considered a part of the local knowledge in the sense that it is rooted in a particular community and situated within broader cultural traditions (UNEP 2008).

MANAGED FOREST

A managed forest is a forest subject to forest management (CPF 2005).

MITIGATION

An anthropogenic intervention to reduce the anthropogenic forcing of the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks (IPCC 2007a).

NATIONAL ADAPTATION PROGRAMME FOR ACTION (NAPA)

The process for preparation of the National Adaptation Programmes for Action was established in the 7th Conference of the Parties of the UNFCCC in 2001. NAPAs identify and prioritize the adaptation needs in the least developed countries (LDCs), and communicate priority activities addressing the urgent and immediate needs and concerns regarding adaptation to the adverse effects of climate change (UNFCCC 2002).

NATIONAL FOREST PROGRAMME (NFP)

A country specific policy and planning framework to achieve sustainable forest management as a contribution to sustainable development. NFP is based on a set of principles, including a participatory inter-sectoral approach for the formulation of policies, strategies and plans of action, their implementation, monitoring and evaluation for the conservation, management and sustainable development of a country's forests (IUFRO 2005).

NATURAL FOREST

Forest stands composed predominantly of native tree species established naturally. This can include assisted natural regeneration, excluding stands that are visibly offspring/descendants of planted trees (CPF 2005).

NON-TIMBER FOREST PRODUCT (NTFP)

All biological materials other than timber, which are extracted from forests for human use. Forest refers to a natural ecosystem in which trees are a significant component. In addition to trees forest products are derived from all plants, fungi and animals (including fish) for which the forest ecosystem provides habitat (IUFRO 2005).

NON-WOOD FOREST PRODUCT (NWFP)

A product of biological origin other than wood derived from forests, other wooded land and trees outside forests (FAO 2008c).

OTHER WOODED LAND

Land not classified as Forest, spanning more than 0.5ha; with trees higher than 5m and a canopy cover of 5–10%, or trees able to reach these thresholds in situ; or with a combined cover of shrubs, bushes and trees above 10%. It does not include land that is predominantly under agricultural or urban land use (FAO 2004).

PLANTED FOREST

Forest stand in which trees have predominantly been established by planting, deliberate seeding of coppicing, where the coppicing is of previously planted trees. Includes all stands established by planting or seeding of both native and non-native species (CPF 2005).

PLANT FUNCTIONAL TYPE (PFT)

An idealised vegetation class typically used in dynamic global vegetation models (DGVM) (IPCC 2007a).

POLAR FOREST DOMAIN

Polar domain experiences long, cold winters and short, cool summers. Mean annual temperature ranges from around –20°C in the most northern part to –7°C in the south; summer mean temperatures range from –6°C to +6°C ; winter mean temperatures from –35°C to –17.5C°. The annual precipitation varies from 100mm to 600mm. Snow may fall any month of the year and usually persists on the ground for at least 10 months (September to June). Permafrost is continuous and may extend to a depth of several hundred meters (FAO 2001b).

POLICY INSTRUMENTS

(= Policy tools) Tools designed to regulate citizens' behaviour and define their legal rights. Substantive policy instruments direct government intervention that required or motivated a certain course of behavioural change. They comprise regulatory (e.g. laws, regulations), financial (e.g. subsidy, taxation) and informational (e.g. education, planning) policy means, which act directly on the addressees. Procedural policy instruments act on the process indirectly through institutional or organisational means by which policy is created. (adapted from IUFRO 2005).

PRIMARY FOREST

Forest of native species, where there are no clearly visible indications of human activities and the ecological processes are not significantly disturbed (FAO 2004).

RADIATIVE FORCING

Radiative forcing is the change in the net, downward minus upward, irradiance (expressed in W m^{-2}) at the *tropopause* due to a change in an external driver of *climate change*, such as, for example, a change in the concentration of *carbon dioxide* or the output of the Sun. Radiative forcing is computed with all tropospheric properties held fixed at their unperturbed values, and after allowing for stratospheric temperatures, if perturbed, to readjust to radiative-dynamical equilibrium. Radiative forcing is called *instantaneous* if no change in stratospheric temperature is accounted for. For the purposes of this report, radiative forcing is further defined as the change relative to the year 1750 and, unless otherwise noted, refers to a global and annual average value. Radiative forcing is not to be confused with *cloud radiative forcing*, a similar terminology for describing an unrelated measure of the impact of clouds on the irradiance at the top of the *atmosphere* (IPCC 2007c).

REFORESTATION

Establishment of forest plantations on temporarily unstocked lands that are considered as forest (FAO 2004).

RESILIENCE

The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change (IPCC 2007).

SCENARIO

A plausible and often simplified description of how the future may develop, based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a 'narrative storyline'(IPCC 2007a). See also climate (change) scenario, emissions scenario and SRES.

SECONDARY FOREST

Forest regenerated largely through natural processes after significant human or natural disturbance of the original forest vegetation.
Explanatory notes:

- The disturbance may have occurred at a single point in time or over an extended period;
- The forest may display significant differences in structure and/or canopy species composition in relation to nearby primary forest on similar sites (FAO 2004).

SENSITIVITY

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate variability or change. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea-level rise) (IPCC 2007a).

SEQUESTRATION (of carbon)

The process of increasing the carbon content of a reservoir/pool other than the atmosphere. (IPCC 2007a)

SRES

The storylines and associated population, GDP and emissions scenarios associated with the Special Report on Emissions Scenarios (SRES) (Nakićenović et al. 2000), and the resulting climate change and sea-level rise scenarios. Four families of socio-economic scenario (A1, A2, B1 and B2) represent different world futures in two distinct dimensions: a focus on economic versus environmental concerns and global versus regional development patterns (IPCC 2007a).

STABILITY (in ecosystems)

A set of self-perpetuating and mutually reinforcing structures and processes that maintains a relatively constant assemblage of forest species (Lewontin 1969 combined with Peterson et al. 1998).

SUBTROPICAL FOREST DOMAIN

The subtropical domains are located between 25 to 40 degrees in the northern and southern hemispheres. They are areas with at least 8 months above the mean monthly temperature of 10°C (FAO 2001b). See Chapter 3 for more detailed description.

SUSTAINABLE FOREST MANAGEMENT

Sustainable forest management, as a dynamic and evolving concept, aims to maintain and enhance the economic, social and environmental values of all types of forests, for the benefit of present and future generations. The seven thematic elements of sustainable forest management are: (a) extent of forest resources; (b) forest biological diversity; (c) forest health and vitality; (d) productive functions of forest resources; (e) protective functions of forest resources; (f) socio-economic functions of forests; and (g) legal, policy and institutional framework. The thematic elements are drawn from the criteria identified by existing criteria and indicators processes, as a reference framework for sustainable forest management (UN 2007).

TRADITIONAL FOREST-RELATED KNOWLEDGE

Traditional forest-related knowledge can be defined as a cumulative body of knowledge, practice and belief, handed down through generations by cultural transmission and evolving by adaptive processes, about the relationship between living beings (including humans) with one another and with their forest environment (UNFF 2004).

TREES OUTSIDE FOREST

Trees outside forests include all trees found outside forests and outside other wooded lands:

- stands smaller than 0.5ha;
- tree cover in agricultural land, e.g. agroforestry systems, homegardens, orchards;
- trees in urban environments;
- along roads and scattered in the landscape (FAO 2004).

TEMPERATE FOREST DOMAIN

The temperate domain is found at middle latitudes – usually between the subtropical domain equator-wards and the boreal domain pole-wards. The boundaries with the subtropical and boreal domain are 8 months and 4 months, respectively, with average temperatures of 10°C or above (FAO 2001b). See Chapter 3 for more detailed description.

TROPICAL FOREST DOMAIN

In the tropical domains the mean temperature of all months is over 18°C. Their approximate location is between the Tropic of Cancer 23°N and the Tropic of Capricorn 23°S (FAO 2001b). See Chapter 3 for more detailed description.

UNCERTAINTY

Where uncertainty is assessed more quantitatively using expert judgment of the correctness of underlying data, models or analyses, then the following scale of confidence levels is used to express the assessed chance of a finding being correct: very high confidence at least 9 out of 10; high confidence about 8 out of 10; medium confidence about 5 out of 10; low confidence about 2 out of 10; and very low confidence less than 1 out of 10.

Where uncertainty is assessed qualitatively, it is characterized by providing a relative sense of the amount and quality of evidence (that is, information from theory, observations or models indicating whether a belief or proposition is true or valid) and the degree of agreement (that is, the level of concurrence in the literature on a particular finding). This approach is used by WG III through a series of self-explanatory terms such as: high agreement, much evidence; high agreement, medium evidence; medium agreement, medium evidence; etc. (Bates et al. 2008).

UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE (UNFCCC)

The Convention was adopted on 9 May 1992, in New York, and signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries and the European Community. Its ultimate objective is the "stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system". It contains commitments for all Parties. Under the Convention, Parties included in Annex I aim to return greenhouse gas emissions not controlled by the Montreal Protocol to 1990 levels by the year 2000. The Convention entered in force in March 1994 (IPCC 2007a). See also 'Kyoto Protocol'.

VULNERABILITY

Vulnerability is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity (IPCC 2007a).

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