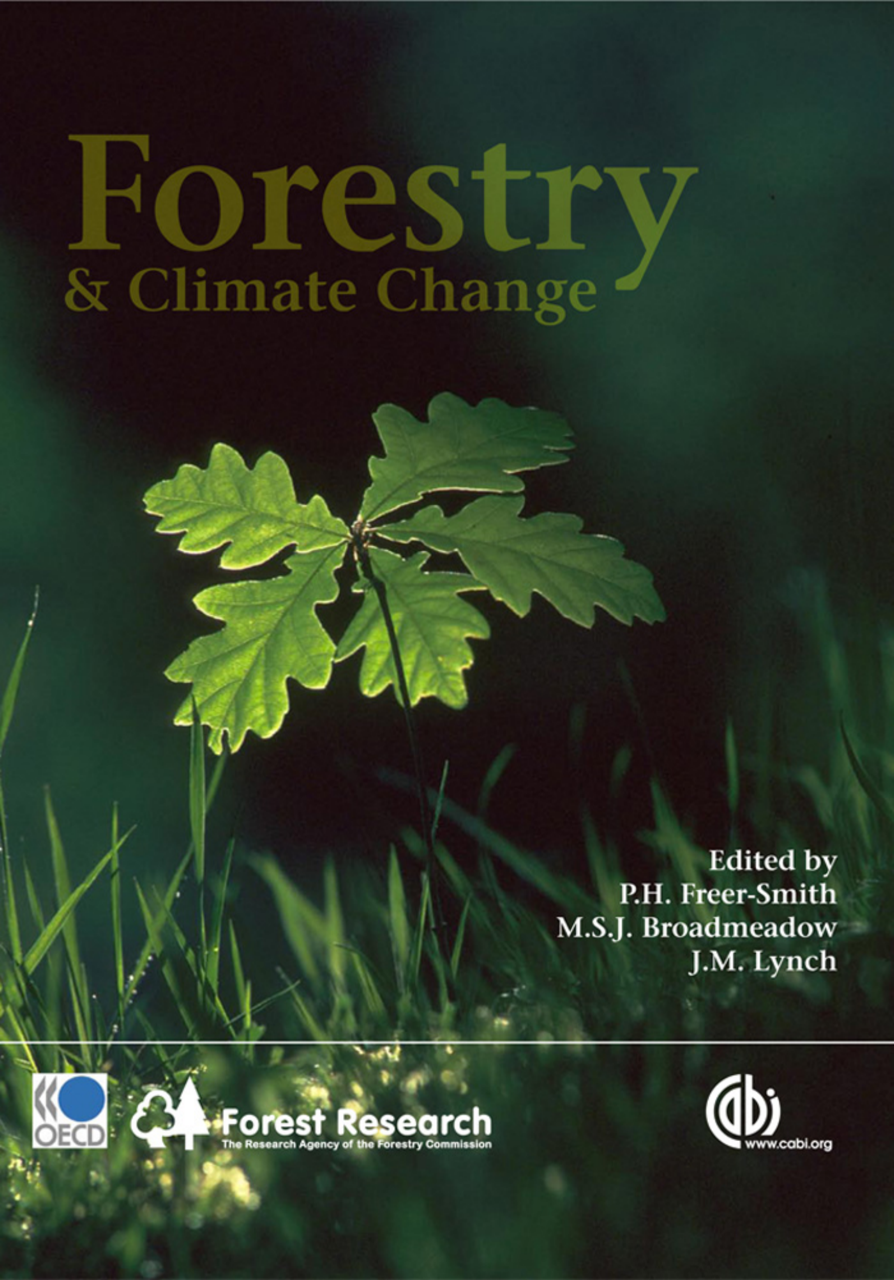

Forestry
& Climate Change

Edited by
P.H. Freer-Smith
M.S.J. Broadmeadow
J.M. Lynch

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FORESTRY AND CLIMATE CHANGE

Front cover Oak (*Quercus*) seedling. With around 500 species, *Quercus* is the most widespread and numerous broadleaf tree genus. Its natural range is across the northern hemisphere and parts of the southern hemisphere, and the genus is represented in temperate, subtropical and tropical regions. (Photo: Laurie Campbell.)

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Foreword – the Global Forestry Challenge

On the 21 November 2006, some of the world's leading scientists and policy makers from the fields of forestry, climate change, biodiversity and bioenergy assembled for an international conference on forestry and climate change. The then Minister of State for Climate Change from the UK's Department for Environment, Food and Rural Affairs, Ian Pearson MP, gave an opening address which laid the foundations for discussions over the following 2 days on how to optimize the forestry sector's contribution. This Foreword is based on his speech which has been updated to reflect recent changes in the international climate change arena.

There is no bigger challenge in the world today than how we respond to the scientific evidence that our climate is warming – for which the human race is responsible. Climate change is not just an environmental issue – it is an economic issue, a social issue, a security issue and, above all, a moral issue. The publication of the Stern Report on the *Economics of Climate Change* destroys the economic argument that we cannot afford to reduce our emissions. Climate change, not action to tackle it, is the greatest threat to growth. The longer we wait, the harder and more expensive it will be. And the costs will be greatest for the developing world.

As the world's first industrialized nation, the UK has a moral responsibility to provide international leadership. Apart from alleviating starvation and avoidable disease, nothing is more important and urgent in the world today than securing international agreement on a long-term future framework, and the actions that are necessary to avoid dangerous climate change. Stabilizing the concentration of carbon dioxide and other greenhouse gases in the atmosphere will take enormous effort. There is widespread recognition that we will have to move substantially beyond the agreements reached at Kyoto in 1997. Our ambitions must be far greater and all key emitting nations must play a full part.

We will not meet this challenge without reducing emissions from deforestation. The future of the world's forests is central to the well-being of the human race and to the well-being of the planet. As we all appreciate forests are the world's 'lungs' and one of our best hopes for heading off dangerous climate change.

Forests support ecosystem services which, in turn, support mankind, providing food, shelter and medicines for the people who live in and near them. Such a precious resource should be guarded jealously, but that is simply not happening. Between 2000 and 2005, more than 7 million ha of forest were lost *every* year – an area the size of Sierra Leone or Panama. This scale of destruction contributes, according to Stern, more than 18% of global emissions, a share greater than is produced by the global transport sector. It destroys plants and species we've barely discovered, robbing mankind of potential medicines. It also causes hardship for many of those people who rely on these wonderful natural resources.

Only now are we beginning to understand what climate change could do to the world's forests and how forest ecosystems regulate local and regional climate. For example, recent research by the Hadley Centre has found that climate change could lead to a significantly drier climate in the Amazon Basin, causing extensive repercussions throughout the South American region.

The UK Government is leading work around the world to protect forest ecosystems and increase our understanding of the impact of climate change on them. The Darwin Initiative – funded by the UK Department for Environment, Food and Rural Affairs – is supporting forestry projects in many countries. For example, it funds the Global Canopy Programme in Malaysia which helps to build human capacity to conserve forest biodiversity. Another project, in Brazil, is quantifying the biodiversity of forests in Amazonia, assessing their value in terms of both ecosystem functions and carbon sequestration. This project will help inform how we can optimize meeting both biodiversity and carbon objectives.

The UK Department for International Development is also active in supporting sustainable forest management. A particular focus is on improving forest governance with a range of projects in Indonesia, Ghana and Cameroon. The UK is a significant donor to the Global Environmental Facility and, through this fund, has contributed to 29 forestry projects in Brazil, covering a range of issues from implementing international conventions and monitoring the effects of climate change to promoting biodiversity.

The UK is also working through the EU to take action and, in 2006, was a key supporter of new EU legislation to prevent illegally logged timber from being allowed into the EU. While all these efforts continue, awareness of the value of forests also needs to be raised – not just their role in mitigating climate change, but the goods and services they provide and their value to human livelihoods and well-being.

Sir Nicholas Stern's review clearly identified that curbing deforestation would be an effective way to reduce carbon emissions but, also, that there were significant economic benefits to local communities from managing their forests sustainably. Curbing deforestation will not be easy to achieve, as powerful socioeconomic forces are the cause of it in many countries. Workable solutions that recognize this must be found. Genuine synergy is needed between land management objectives and local community involvement, at both national and international levels. The UK has worked actively with developing countries, with Germany who holds the Presidency of the G8, and with the World Bank, to secure agreement at the G8 Summit in Heiligendamm to support the development of a pilot scheme to test incentive-based mechanisms for reducing deforestation while maximizing the benefits for biodiversity, and for building capacity. The UK will continue to explore how we can mobilize international resources to help developing countries manage their forests in ways that help to reduce carbon emissions. One option to explore further is whether linking forest protection with carbon markets could provide more sustainable investment over the longer term. Deforestation policies should be shaped and led by the nations where forests stand, but there must be help from the international community. Of paramount importance is the need for an international framework for achieving sustainable forestry. COP12 in Nairobi in November 2006 saw all 189 parties to the UN Framework Convention on Climate Change working together on such a framework. These discussions are ongoing and there is growing confidence that an agreement on the way forward will be achieved at COP13 in Bali in December 2007.

In conclusion, the demands placed on the world's forests are great – and growing. Striking a balance between their protection and sustainable use, while increasing the share of benefits to the people who live in and around forests, poses many challenges. Such a solution is achievable and the prize is worth the effort – not just for the emissions reductions but also for the other livelihood, environment and biodiversity benefits. The UK has put enormous effort into the science of climate change and the climate change negotiations, including those elements of the agreement concerning forestry and land use. It is critical that we all continue to do our best to advance environmental sustainability in all these areas in the future.

This publication is timely in drawing together current thinking on how the global forestry community can respond to the threat posed by climate change. Through improving understanding of the social, economic and environmental factors that drive deforestation, effective proposals that inform action to reverse it can be developed and help us rise to the challenge of effectively countering climate change.

I

Introduction

‘Climate change is one of the greatest challenges we face – both in terms of its potential impacts on our societies and the earth, and in terms of the scale of the international co-operation that is needed to confront it.’ ‘The OECD and Forestry Commission have gathered together scientists from 16 countries, including those that have the largest forest areas, to discuss the contribution that the forestry sector can make to meet this great challenge.’

The Rt. Hon. Lord Clark of Windermere
Chairman of the UK Forestry Commission
Tuesday, 21 November 2006, Wilton Park

In Chapter 2 (Forests and Climate Change: the Knowledge-base for Action) and in the short introductions to the sections which follow, we have explained the logic and sequence of this book. We hope that Chapter 2 pulls out some of the key observations and provides a steer to where critical issues are set out in greater detail in the 26 chapters which follow.

1

Personal Introduction by The Rt. Hon. Lord Clark of Windermere

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I would like to thank all those who travelled to Wilton Park to work on forestry and climate change. This really was a working conference, where many participants gave presentations, chaired workshops and assisted in reporting. The conference was organized by Forest Research, the Forestry Commission's research agency, on whom we depend so much, not only for scientific research but also for advice at all levels. Peter Freer-Smith, Mark Broadmeadow and Jim Lynch took the lead in organizing the meeting and in the production of the book inspired by this conference.

I would also like to thank OECD for co-sponsoring the conference. In the UK the subject of climate change was often headline news during 2006 and recently Sir Nicholas Stern's report *The Economics of Climate Change* (The Stern Report) has been published. Commissioned by the UK Government, this report highlighted an urgent need for action. Thus the timing for an OECD Conference on Climate Change and Forestry could not have been better. Climate change is a concern to governments and international organizations across the world, and this conference helped us to identify the part that forestry can play in addressing this important global concern.

I was very pleased to learn that OECD's Secretary-General, Angel Gurría, has been so supportive of Sir Nicholas's report, and has congratulated both our former Prime Minister Tony Blair and the former Chancellor of the Exchequer Gordon Brown for commissioning the study and for making it freely available. Secretary-General Gurría reminded us that the OECD has been pressing its member states to take action on climate change for many years, in particular, to look at more market-based solutions to deal with carbon emissions. He has told the UK Government that the OECD is very willing to contribute to the detailed action programme needed to tackle the potentially devastating consequences of climate change.

Climate change is one of the greatest challenges we face – both in terms of its potential impacts on our societies and the earth, and in terms of the scale of

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the international cooperation that is needed to confront it. But a major barrier to the effective application of these policies, and their adoption in other countries, is a fear that they will negatively impact on a country's economic competitiveness. So if one country takes a lead will its competitors then benefit by continuing as they are?

I suspect that there is competitive advantage in good environmental practice, but we are only going to make a difference through collaboration, the sort of collaboration that we saw at Wilton Park in November 2006. The OECD and Forestry Commission have gathered together scientists from 16 countries, including those that have the largest forest areas, to discuss the contribution that the forestry sector can make to meet this great challenge. Let us not forget that although climate change is a potential disaster at a global scale that disaster will be played out locally, affecting communities and individuals. And the people most affected will be the people least able to cope – poor people in poor countries. So this is not a simple economic or scientific challenge, but is closely linked to international efforts to reduce poverty and promote stability and prosperity.

So where does forestry fit into all this?

- As the Stern Report tells us, deforestation accounts for just under a fifth (18%) of all the carbon dioxide released into the atmosphere.
- In the past 3 years the world has lost an area of forest that is greater than the area of the UK. If we use gross area cleared, rather than net area, then we can include Ireland, the Isle of Man and the Channel Islands as well!
- However, the story is not all bad and in some regions there is a very considerable expansion in forest cover, amounting to almost 4 million ha. From this I believe we can say that global forest decline is not inevitable, positive action will yield results. We can look to Asia for leadership here, where a net loss of some 800 000 ha a year in the 1990s has been turned into a net reported gain of 1 million ha a year for the past 5 years, primarily as a result of large-scale afforestation reported by China.
- When the public think of forestry, what probably comes to mind is an image of a tropical jungle, but more than half of the world's forest area is found in five countries (the Russian Federation, Brazil, Canada, the USA and China), of which only one is tropical.
- It is worth remembering that just ten countries account for two-thirds of global forest cover. So there is a possibility to act strategically. I suggest that we could see change come about in a surprisingly short time if we can go about things in the right way.

There is simply no argument that deforestation is currently concentrated in the tropical and subtropical regions. Does the developed world – for example the OECD member countries – have a role? There are many things that we can do.

- First, we can continue to make our industry effective and efficient. This means optimizing our use of raw material, increasing the efficiency of our operations, producing bioenergy in a variety of forms and perhaps expanding into biorefinery products where we substitute fossil fuel and feedstocks with renewable alternatives. By developing the competitiveness of our sector we will ensure both a commercial and environmentally sound future.

- We can demonstrate what can be done through best practice. For example, FAO reports that the forest products industry is itself a major consumer of energy, using 6% of total industrial energy. In my Department, the Forestry Commission, Tim Rollinson our Director General has established a project team to look in detail at the way that we use resources. He has asked them to give him recommendations for reducing our environmental footprint.
- Globally the forestry and wood products sector is the only sector that already generates approximately 50% of its own energy needs, the majority from renewable carbon-neutral biomass. Energy costs, energy supply and climate change are intricately linked to the future of the forest products industry. But in addition to renewable energy let us also think about the potential of renewable products based on wood, in building especially but also packaging.

OECD countries generally, and I speak from detailed knowledge of UK forestry, have become expert at delivering sustainable forestry practice. We know how to translate theory into action and we know how to measure the impact of our activities and report on them – to tell society how we are progressing and back this up with independent verification.

Deforestation is driven mostly by social and political factors. Good governance, empowerment of the wider community of stakeholders in forest management, stability in forestry institutions are some of the areas where we can help. Can we make our forests too valuable to fell? Many of our pressing environmental problems would be reduced if we could overcome the dilemma where the environmental services that the human race depends on do not generate any tangible benefit – I mean money – for the stewards of those services. I was struck by a recent FAO report on the value of forests, where the authors said that if the true value of forests was properly understood then governments would think that they were too valuable to clear. We are starting to see some developments here. For example our co-sponsors, OECD, strongly support the development of market-based approaches such as markets linked to carbon emissions, and this is a step towards monetizing the previously untraded benefits from forests.

Environmental regulation can be a powerful force in driving innovation, and there is a surprising consensus on this. The Stern Report recommends a combined approach of environmental regulation and taxation to drive forward innovation and resource efficiency through market forces. There are already very good international networks in all branches of the forestry and wood products sector covering policy, science and practice. And there is probably a lot more science going on than we realize. In the Forestry Commission we recently estimated that through its Agency, Forest Research, the Commission is spending about a million pounds (2 million dollars) every year on research that is directly relevant to climate change. Surely there is scope for greater collaboration in this area, in Europe and more widely, so that we can get the greatest leverage from this activity; I would be very pleased to see proposals for how we can help encourage this.

This conference focused on how the forestry sector needs to respond to the current understanding of climate change with new policies and with innovative practice. This is not an easy task. Forestry does not operate in a vacuum, so an integrated and holistic approach is needed. This is a challenge because current international and national arrangements have evolved in such a piecemeal way over the years. The meeting focused particularly, of course, on the responses required in OECD countries. This means an emphasis on temperate and boreal forest systems but in the context of global concerns and international policy. Our science agenda surely must be about the global ecosystem and concerned as much with the future as with the present.

I finish by again thanking all those who came to Wilton Park. If the conference and the proceedings in this publication make even a very small contribution it will be immensely worthwhile, and we will be thanked in times to come.

2

Forests and Climate Change: the Knowledge-base for Action

P.H. Freer-Smith, M.S.J. Broadmeadow and J.M. Lynch

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Introduction

Forests make up around 30% of the world's land surface, and forest ecosystems, including their soils, store approximately 1200 gigatonnes of carbon which is considerably more than is present in the atmosphere (around 762 GtC). A major anthropogenically driven climate change is under way (IPCC, 2007) and this is largely being caused by changes to the global carbon cycle through the emission of carbon dioxide and methane. Clearly, the interactions between forest ecosystems and the atmosphere are critically important.

Together with global political and security issues, climate change is now accepted as being of overriding importance to the future of the world's environment and natural systems and of human society. In the international dialogue on the environment and climate the role of forests in influencing earth systems, including climate and carbon (C), nitrogen (N), hydrological and other geochemical cycles, has not emerged to date as an area for major action, although there are real signs that this is changing. This – the role of forests in climate change – is the principal issue addressed here and, in this publication, it is considered as two related questions:

1. How do forests interact with the other components of the physical and natural world and with human society?
2. How can we manage forests globally to make the most of their contribution to mitigation of climate change along with the established objective of sustainable management to maximize the full range of economic and non-market benefits which forests provide?

The first of these questions is addressed through examination of the science, principally in three sections: Section II: Climate Change, Forestry and the Science–Policy Interface; Section III: Forestry Options for Contributing to

Forestry and Climate Change
(eds P.H. Freer-Smith, M.S.J. Broadmeadow and J.M. Lynch)

Climate Change Mitigation; and Section IV: Impacts of Climate Change on Forests: Options for Adaptation. To address the second question it is necessary to consider the international framework which has been established for forestry and the various international conventions which impinge on forest ecosystems. These issues are introduced in Section I and returned to in Section V: National and International Frameworks: Current and Future Policy and Section VI: Implications for Future Forestry and Related Environmental Development Policy. This final section focuses particularly on the way forward.

Woodlands are an integral element of the landscape. They provide natural habitats, enhancing the biodiversity of predominantly managed, agricultural and urban landscapes and are a potential source of both renewable energy and timber. Woodlands also have a role to play in natural resource protection through flood alleviation, improvement of water quality and soil erosion control. Like all natural systems, woodlands are vulnerable to the impacts of climate change, and the forestry sector needs to respond strategically to the threats posed by such change. Woodland establishment and management have long planning horizons, making a coherent strategic response particularly important in forestry. However, strategic planning, with the objective of adapting to climate change, creates tensions, partly because of the multiple objectives of modern forestry, but also because of the uncertainty associated with climate change projections and their likely impacts. The challenge is to develop a strategic response that both maximizes the contribution of woodlands to climate change mitigation and optimizes natural resource protection. The overall objective of the Wilton Park Conference was to identify how the forestry sector (national and international) needs to respond to the current understanding of climate change. Climate change, both through impacts on forests and because of the potential for carbon sequestration, impacts in all areas of forest planning and management from species choice through to timber utilization. Because forests must deliver multiple objectives (ecological, environmental, recreational, social together with economic/commercial), developing a strategic response to climate change mitigation and adaptation must also be multi-sectoral.

In writing this introduction we are particularly struck by the quality of scientific information presented and by the way that this knowledge-base is focused to identify and guide the actions now needed. The Wilton Park Conference, in November 2006, on this subject was timely and inspiring. We hope that this book expresses and represents the interest and excitement that were generated.

Climate Change, Forestry and the Science–Policy Interface

Comprehensive and critical review of the scientific evidence-base on climate change and related earth systems has been, and continues to be, provided by the Intergovernmental Panel on Climate Change (IPCC). The scientific consensus that there is an ongoing anthropogenic influence on the global climate was first set out as long ago as 1995 in the IPCC's Second Assessment Report in the historic phase '… the balance of evidence suggests a discernible human influence on global climate'. Many of the chapters in our publication draw on data from the

IPCC Third Assessment Report (TAR; IPCC, 2001) which is a detailed, highly credible and authoritative source. During 2007 the IPCC has published its Fourth Assessment Report with the first Working Group releasing its findings on 2 February 2007 (IPCC, 2007). Over 600 scientists from 113 countries have been involved in producing this fourth report, and the scientific evidence can now be regarded as 'unequivocal'. The tone of IPCC reports has shifted to one of very high confidence in the science. This is made clear by just two sentences quoted from the February 2007 report:

> 'Since the TAR, progress in understanding how climate is changing in space and time has been gained through improvements and extensions of numerous datasets and data analysis, broader geographical coverage, better understanding of uncertainties, and a wider variety of measurements.' 'Warming of the climate system is *unequivocal*, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level.'

The report warns that average world surface temperature could rise by 3°C by 2100, and possibly even more, if no measures are taken to reduce greenhouse gas (GHG) emissions to the atmosphere. Behind the science the message is clear: time is running out faster than the scientific community initially thought it would; it is now time for action.

The evaluations presented in the various chapters of this book draw on the IPCC's publications. In most cases our contributors have been involved in the IPCC's work but, in this book, their focus moves quickly to the data and conclusions which relate to forest/climate interactions and to the implications for forest science, policy and thus management. Internationally, forest science is drawn together by the International Union of Forest Research Organisations (IUFRO) which is loosely parallel, and certainly complementary, to the IPCC. Again, IUFRO's knowledge-base is drawn on significantly here and most of the forest scientists who have contributed chapters are active IUFRO members.

The science of climate change has made major progress in the past 15 years, providing a new understanding which has been effectively communicated to the public and, arguably, to policy makers. Forest science has progressed steadily, benefiting from the increasing public concern for the environment, and with public attention focused particularly on tropical deforestation. International frameworks focused around the United Nations Conference on Environment and Development (UNCED) programme (1992 onwards) and now the UN Forestry Forum have provided an arena for science–policy interactions. The progress made within these fora and the related processes of establishment and implementation of the Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) have been considered in the policy-focused chapters in Sections II, V and VI. In Section II, Burley *et al*. (Chapter 5) describe the three flexible mechanisms which are in place to help achieve the targets for GHG emission reductions of the Kyoto Protocol and the way in which these mechanisms have created an international market for Certified Emission Reduction credits.

We are pleased that many of the chapters presented here place major emphasis on the future, particularly on what we should do in the immediate future and mid-term. Some of the science featured here was 'breaking news' at the time the book was compiled. These exciting and inevitably new insights and established, well-supported and clearly stated science, often have a significant influence on recommendations for the way forward. In the discussion which follows we have attempted to highlight some of those critical areas of science – both the new and the well established but highly relevant.

Twenty-five years of research have substantially increased our knowledge of the global carbon cycle. The budget suggests that the terrestrial biosphere is a sink comparable in size to the oceans. Equally important is the observation that coupled carbon cycle–climate models show simulated climate change reducing the strength of the carbon sinks in both the oceans and on land – a critical positive feedback (Heimann, Chapter 3). The past 25 years have also seen major change in the forest industry worldwide. In developed countries the forestry industry has undergone a radical shift of emphasis away from commercial production forestry to better consideration of the wider benefits, and thus to sustainable forest management implemented through national forest plans, forestry standards, commitments under international conventions and certification systems. Because of the costs associated with production of timber (roundwood), a steady shift in the regions of the world used to provide the raw material for production of sawn timber and pulp started in the early 1980s. Commercial forestry has moved its operations, to a significant extent, from boreal and temperate forests to fast-growing tropical and subtropical regions. However, plantations are increasingly used to produce roundwood, and it is estimated that by 2050 as much as 75% of all industrial roundwood might come from plantations. It is also fascinating to consider that if all roundwood was sourced from effectively managed plantations only some 73 million ha of land would be required. That is, only 2% of the world's forest area would be enough to satisfy the current global needs for roundwood (Seppälä, Chapter 4).

Forestry Options for Contributing to Climate Change Mitigation

The major importance of forests in the world's carbon cycle, along with the substantial and ongoing changes in the global forest sector (economic and non-market), provides a very real potential for forestry to contribute to the mitigation of climate change. Section III focuses on the various mechanisms by which this contribution might be delivered. The UK Government report on the economics of climate change (Stern, 2006) gave a clear message that acting to lessen the impacts of climate change now is a far better economic strategy than management of the social and economic crises that will arise if mitigation measures are not taken. The Stern Report also provided specific authoritative proposals, one of which related directly to global forest management. Land-use change, principally deforestation, accounts for some 18% of CO_2 emissions (IPCC, 2001). Stern sees carbon (C) emissions from deforestation (particularly in the tropics), as a significant and tractable component of anthropogenic emissions. Some of the C lost through deforestation is offset by reforestation and afforestation (Schlamadinger, Chapter 10). A number of countries have experienced transitions from deforestation to reforestation and, more controversially, there appears to be a relationship between gross domestic product and the recorded change of forest growing stock. Important variables in considering this relationship are national forest area, growing stock per unit area, biomass per unit growing stock volume and carbon concentration in biomass (Kauppi *et al.*, 2006). There is also good experimental and modelling evidence that the net ecosystem production (NEP) of standing boreal and temperate forests will be maintained or even increase as climate change proceeds (Jarvis and Linder, Chapter 9). The inventory approach supports this general view in showing that forests above a variable age threshold are usually net carbon sinks, although there are interesting spatial and temporal variations of sink and source strength (Nabuurs *et al.*, Chapter 13). The modelling work of the ATEAM project (Eggers *et al.*, Chapter 14) suggests that European forests will remain a strong carbon sink for several decades with the size of this sink influenced by wood demand. Climate change is predicted to have a positive impact on growth but if management does not respond to this there could be major problems of biotic and abiotic damage.

In addition to the sustainable management and protection of forests, and to the prevention of deforestation, detailed consideration is given to product substitution and woodfuel as carbon-lean approaches to the provision of raw materials for construction and energy generation (Matthews *et al.*, Chapter 12). Bioenergy forestry systems and the active removal of carbon from the atmosphere by forestry systems is introduced by Sims in Chapter 11. Woody biomass is currently used to a varying degree geographically for cooking, heat, electricity and in co-generation plants, and in future may be sought after for biofuel processing, in biorefineries and hydrogen production plants. However the role that woodfuel will play in future energy supply will depend on overcoming the current barriers to project development and to commercial investment. Sims provides an authoritative evaluation of these. In Chapter 8, Brown and Kurz make a serious analysis of why the implementation of forest mitigation activities has lagged behind their perceived potential. The inclusion of forestry activities in carbon trading schemes and in the Clean Development Mechanism of the Kyoto Protocol are both discussed. It is hoped that over the coming decades the greenhouse gas mitigation benefits of well-managed forestry schemes and of wood substitution for fossil fuels will become better understood, and that such schemes will gain public acceptance.

In a number of countries there are now schemes which allow individuals and businesses to offset their carbon emissions by tree planting. There is ongoing controversy over the value of such schemes relative to the apparently more obvious benefits of emissions reduction. Carbon offset schemes – depending on how they are managed and on the end use and life cycle of any products – may provide an additional benefit and indeed a new incentive for the creation and protection of multi-purpose woodlands. But this is a very different approach to that of planting trees solely for carbon sequestration. Governments and international organizations need to work with stakeholders to provide and improve the standards and guidance on forestry so that these encompass carbon offset schemes and to ensure that such schemes are robust, providing consumers and customers with assurance of their effectiveness.

Impacts of Climate Change on Forests: Options for Adaptation

The current role of forests in mitigating the impacts of climate change and their potential in future mitigation are both dependent on the impacts of ongoing climate and environmental change on forest ecosystems. These direct impacts of climate change are examined in Section IV. The model predictions presented in Chapter 18 by Loustau *et al*. illustrate the dramatic changes in the geographical distribution of 'climate space' for tree species in temperate and Mediterranean regions. The possibility of significant forest dieback in tropical regions and from wider environmental problems including air pollution, drought, wildfire, melting of permafrost and insect and pathogen outbreaks in other regions are considered in a number of the chapters of Section IV, particularly Reichstein (Chapter 16) and Solomon and Freer-Smith (Chapter 19). The latter also discusses the interactions between biological and abiotic factors. Widespread forest dieback would represent a strong positive feedback for climate change and this possibility has been considered in a limited number of the climate prediction exercises (Heimann, Chapter 3; Reichstein, Chapter 16). Adaptation measures to increase the resilience of forest ecosystems to climate change are explained in several chapters, including Solomon and Freer-Smith (Chapter 19), Loustau *et al.* (Chapter 18) and Broadmeadow and Carnus (Chapter 26). These measures and the policy barriers to their effective implementation clearly need to be addressed and resolved if the forestry contribution to climate change mitigation is to be maintained and fully realized.

The direct effects of elevated atmospheric carbon dioxide (CO_2) concentrations on trees (Karnosky *et al.*, Chapter 17) are likely to be one reason for the current increases in standing biomass of European forests (and potentially in other regions), although there are certainly other factors operating. Changes in tree growth rates, in environmental factors including soil moisture deficit, storm and fire frequency and in the severity of pest and pathogen outbreaks will also have major impacts on soil systems, both physically and biologically. In boreal forest systems there is as much as five times the quantity of carbon stored in the soil as in above-ground biomass, while in tropical systems the ratio is, typically, closer to unity (Schepers and Lynch, Chapter 15; Reichstein, Chapter 16). Soil carbon must therefore be considered along with the wider role of soils in terrestrial and aquatic systems.

National and International Frameworks: Current and Future Policy

In Section V, and in two of the earlier chapters, the difficult questions of how international actions interact with national sovereignty are discussed and some specific difficulties associated with the operation of the current international conventions are outlined (Jauregui, Chapter 22; Dresner *et al.*, Chapter 6; and Filho, Chapter 7). Perhaps the most optimistic element of this discussion is the decision of the UN Forestry Forum in February 2006 to work towards the adoption of a non-legally binding instrument on forests at UNFF7 (2007). The policy objectives of sustainable forest management and of forest conservation and the need to identify climate change impacts and to monitor forest carbon stocks require effective forest monitoring systems. The effectiveness of the current systems which depend on national monitoring data submitted to regional (e.g. EU and the Secretariat of the Ministerial Convention on the Protection of Forests in Europe) and international (e.g FAO's Global Resource Assessment) data management centres becomes critical (Holmgren and Marklund, Chapter 20). Similarly, the effectiveness of carbon accounting within the Kyoto Protocol as set out in the Land Use, Land-use Change and Forestry (LULUCF) discussions becomes increasingly important as forest carbon is considered part of national compliance with GHG emissions reduction targets. In much of the developing world there are direct links between poverty and land-use policy, including deforestation, and in Chapter 23 Badiozamani discusses rural development and forestry policy with a focus on Latin America, the Caribbean, Asia and Central Africa. Monitoring and reporting need to address the assessment of forest degradation and land-use change, and the political and economic contexts vary considerably among countries. International instruments will need to be supported by financial measures to ensure that the resultant actions, whether national or programme-based, support local social and economic development goals and ensure long-term health and vitality of people and forests. Examples are given of barriers to the implementation of integrated climate change, and Teplyakov (Chapter 21), Solomon and Freer-Smith (Chapter 19) and Eggers *et al*. (Chapter 14) also describe the notional initiatives and processes which support climate change/forestry policy.

The Way Forward

Section VI (Implications for Future Forestry and Related Environmental and Development Policy) addresses future policy – forestry, environmental and development – with four chapters based on workshops held during the course of the Wilton Park conference and a final chapter which draws these discussions together. The four workshops considered Risks and Uncertainties (Harper and Swift, Chapter 24), Governance (Sangster and Dudley, Chapter 25), Forest Sector Responses (Broadmeadow and Carnus, Chapter 26) and Commercial Projects and Research Initiatives (Hanson and Kurz, Chapter 27). This final section of the publication presents an exciting picture. The forestry sector believes that a change is needed and is imminent and that forestry has an important part to play. There is a continuing and rising global demand for both sawn timber and woodfuel, and, in many regions, data show increased forest growth rates. Furthermore, harvesting is lagging behind increment, and standing volumes (and thus carbon stocks) are increasing. The protection of forests through designations and certification schemes is becoming more commonplace and in some regions forest cover is increasing. Although the net change of global forest area remains a significant and worrying annual loss, the rate of loss of total forest area is decreasing. There is a real expectation that forests will increasingly be able to meet the demands of society for a range of services.

Change is occurring rapidly and is driven largely from outside the sector; for this and other reasons there are some key issues to be resolved if forestry is to make the contribution which it has the potential to fulfil. Much of the evidence-base for these views is presented in this publication. The chapters that follow on from this introduction indicate how forestry may be able to provide not only the multiple and sustainable benefits which can perhaps now be regarded as an established role, but also contribute to the mitigation of climate change. Climate change science, as summarized by the IPCC and here, shows unequivocally that a number of actions are urgent, or indeed overdue, and the evidence presented makes it absolutely clear that forestry is a sector that is ready to take action at a global scale. Undoubtedly there is frustration that, for example, UNFCCC and Kyoto negotiations and the formulation of guidelines on forestry action have been so drawn out that forestry features little in carbon trading, that net global forest cover continues to decline at an alarming rate and that the international framework on forestry appears to have gone over the same ground again and again without finding a way forward. It is increasingly recognized that taking action to protect forests is too important to wait until the next commitment period of the Kyoto Protocol (i.e. after 2012). New institutional, financial and market mechanisms are needed to mobilize new resources and allow implementation of sustainable forest management, as discussed by Rollinson in his conclusions (Chapter 28).

The forestry sector believes that it must and can now make progress, and this publication is effective in presenting the data to support this position. The last Sections (V and VI) identify the overall objectives and point to the next steps. We see forestry as having a crucial role to play and are of the view that forest science and the science–policy interface are now poised to implement a new framework for delivery, but that there is a real need for leadership. We hope that this publication presents a sound knowledge-base, provides a strong steer and will increase the momentum for change.

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II

Climate Change, Forestry and the Science–Policy Interface

'Climate change is the most severe problem that we face today – more serious even than the threat of terrorism.'

Sir David King
UK Government Chief Scientist
Science, volume 303, issue 5655, 176–177, 2004

This section presents the scientific and policy context of the more focused information which is presented in Sections III, IV, V and VI. It covers the global carbon cycle, changing forestry sector, carbon sequestration/trading and the science–policy interface.

3

Present and Future Carbon Sources and Sinks

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Introduction

Precise measurements since 1958 of the concentration of the atmospheric greenhouse gas carbon dioxide (CO_2) show a steady increase from 315 ppm to over 380 ppm today. The reconstruction of these observations over the past 1000 years, based on measurements from air entrapped in ice cores, documents preindustrial concentration levels around 280 ppm followed by a rise clearly paralleling the industrial revolution since 1800. There is now ample scientific evidence that the anthropogenic burning of fossil fuels (coal, oil and gas) is the major cause of the observed increase.

In the 1960s it had already been found that only a fraction of the emitted CO_2 accumulates in the atmosphere, the remainder being taken up by sinks at the earth's surface. As already hypothesized over 100 years ago, the world's oceans are taking up a significant fraction through air–sea gas exchange, reaction with the oceanic dissolved carbonate ion system and transport to depth by currents and mixing. Only after 1980 did it become clear that the terrestrial biosphere also has to be considered as an important term in the global atmospheric carbon balance. It was realized that conversions of land use, primarily deforestation in the tropics, induce substantial terrestrial carbon losses to the atmosphere, which also have to be compensated for by hitherto unknown terrestrial sink processes in order to close the global budget.

Global carbon cycle research over the past 25 years has substantially increased our knowledge on the multitude of complex processes that have to be taken into account in order to follow the flow of carbon though both the marine and the terrestrial domain. Despite this complexity, a simplified global picture as portrayed in Plate 1 can be drawn (Sabine *et al.*, 2004).

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The Contemporary Carbon Budget

The global atmospheric CO_2 budget is shown in Table 3.1, separately for the last two decades of the 20th century, as well as for the recent 2000–2005 time period (Denman *et al.*, 2007). The last column shows the long-term (25-year) average budget for 1980 to 2005. The indicated errors correspond to 1-sigma uncertainty of the global flux estimates. The sign convention is that positive numbers indicate fluxes into the atmosphere.

Over several years, the atmospheric carbon content increase can be determined very accurately from the current observation network. Also the industrial emissions are relatively well defined from statistics of energy production and use (they also include a small but growing contribution from CO_2 emissions in cement production). The global net carbon uptake by the ocean can be determined quite accurately using a number of methods: direct ocean inventory measurements; analysis of the combined atmospheric oxygen and CO_2 budget; analysis of oceanic analogue tracer observations; direct air–sea flux observations; numerical ocean model simulations. On the other hand, the net carbon uptake by the terrestrial biosphere as given in Table 3.1 is not determined from direct observations, but has to be inferred by closing the global atmospheric carbon budget; on decadal timescales, the net land uptake is about 50% smaller than the ocean uptake.

Estimating the emissions of CO_2 from changes in land use is more uncertain. It involves the compilation of the history of changes in land areas used, e.g. for agriculture and pasture as well as a book-keeping model describing the changes in the various carbon pools during and after transitions. The global, decadal averaged numbers given in Table 3.1 are derived from FAO statistics of land use by Houghton (2003). Numbers in parentheses indicate ranges estimated using different techniques, e.g. by the use of remote sensing data (Achard *et al.*, 2004). Although these ranges are rather large, there are several arguments for believing that the high-end numbers are unlikely. Taking the nominal land-use change flux at face value, the carbon balance of the terrestrial biosphere implies residual,

Table 3.1. Global carbon budget in GtC yr $^{-1}$ for different time periods. Errors correspond to one standard deviation; numbers in parentheses reflect estimated ranges. NA: no range estimates available.

	1980s	1990s	2000–2005	1980–2005
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.1	4.1 ± 0.1	3.5 ± 0.1
Industrial emissions (fossil fuel + cement)	5.4 ± 0.3	6.3 ± 0.3	7.2 ± 0.3	6.2 ± 0.3
Net ocean-to-atmosphere flux	–1.8 ± 0.8	–2.2 ± 0.4	–2.2 ± 0.5	–2.0 ± 0.5
Net land-to-atmosphere flux	–0.3 ± 0.9	–1.0 ± 0.6	–0.9 ± 0.6	–0.7 ± 0.6
Partitioned as follows:				
Land-use change flux	1.4	1.6	1.5	1.5
	(0.4 to 2.3)	(0.5 to 2.7)	NA	(0.5 to 2.5)
Residual land sink	–1.7	–2.6	–2.4	–2.2
	(–3.4 to 0.2)	(–4.3 to –0.9)	NA	(–3.8 to −0.6)

compensating sinks on land, which are comparable in size to the net annual ocean uptake fluxes.

Temporal Evolution of the Global Budget

The temporal evolution of the global atmospheric CO_2 budget for the time period of direct observations (1959–2005) is shown in Fig. 3.1. The industrial emissions are derived from global statistics of energy use and cement production (Marland *et al*., 2006, updated with data from British Petroleum, 2006). It is seen that the fossil emissions in 2005 had already reached a level of 7.9 Gt yr^{-1}.

The emissions are cumulatively partitioned into:

1. Ocean uptake as derived from an ocean model (Wetzl *et al*., 2005) which closely matches the global decadal budgets given in Table 3.1.
2. Atmospheric accumulation as derived from the average of the atmospheric measurements at the Mauna Loa, Hawaii and the South Pole station (Keeling and Whorf, 2005).

The difference in the fossil fuel emissions shows the implied global net terrestrial biosphere carbon balance (green). The land-use change flux (Houghton *et al*., 2003) is added on top of the fossil fuel emissions curve. The land sink shows a much larger interannual variability than the ocean sink, the fossil or the land-use

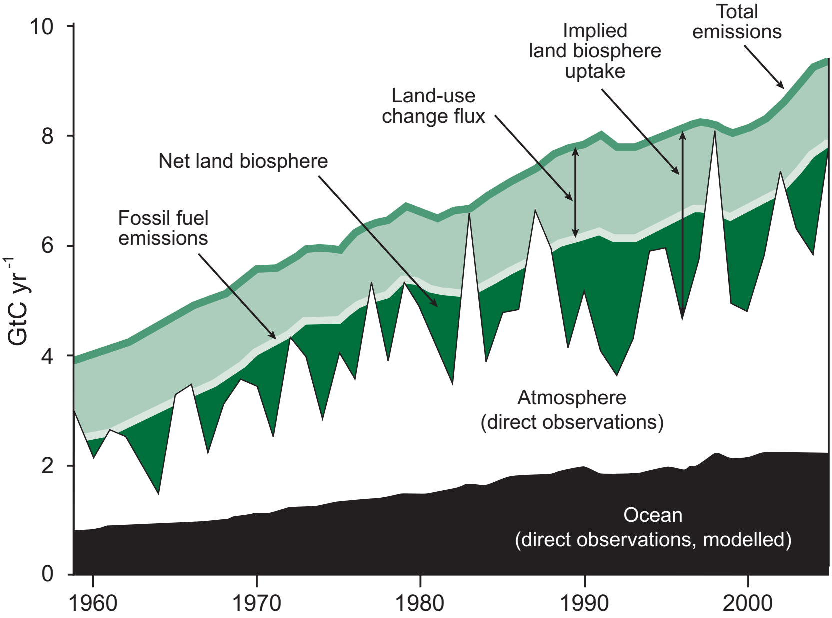

Fig. 3.1. Temporal evolution of the global atmospheric CO_2 budget for the time period of direct observations. The light green line shows the level of the fossil fuel emissions, and the upper darker green line the total emissions (fossil fuel + land-use change flux). The black, white and green colours indicate the partitioning of the total emissions into the oceanic, atmospheric and terrestrial biosphere reservoirs.

CO_2 emissions. The strong global interannual variability seen in the atmosphere is clearly related to climate anomalies, e.g. to the El Nino–Southern Oscillation or, during the 1990s, to the anomalous climate observed after the Mt Pinatubo eruption in 1991. There is ample evidence that it is caused by terrestrial CO_2 exchange processes.

The so-called 'airborne fraction', i.e. the fraction of the total carbon emissions (fossil + land-use flux) accumulating in the atmosphere, on decadal average, has remained remarkably constant during the 45 years of direct atmospheric observations, at a value of about 40%. This is an indication that the global carbon cycle's response to the anthropogenic perturbation is still in the linear range and nonlinearities or climate related feedbacks are not yet discernible.

Latitudinal Distribution of Terrestrial Sinks – Tropics vs Northern Extra-tropics

Additional information on the nature of the carbon sources and sinks can be gained by analysing the large-scale spatial patterns that can be deduced from the global network of atmospheric observations. This method, often called the 'top-down' or atmospheric inversion approach, necessitates the use of a numerical model of atmospheric transport in order to relate the concentration measurements to the sources and sinks at the surface of the earth. Because the global network of observing stations does not comprise more than a few hundred stations, this approach is highly underdetermined and allows at present robust net surface–atmosphere flux estimates only for very large areas.

A global breakdown of net surface fluxes between the tropical region (delimited at 30°N and 30°S) and the extra-tropical regions as estimated by three recent inversion studies is shown in Plate 2. The difference between the inversion studies reflects the robustness of the method. The individual uncertainty of the estimated fluxes averaged over these latitude bands is difficult to assess; for the tropical region it is in the order of ± 1 GtC yr^{-1}.

The coarse, large-scale inversions (Gurney *et al.*, 2003; Peylin *et al.*, 2005) exhibit a larger northern extra-tropical terrestrial sink (> 2 GtC yr^{-1}) as compared to an inversion with higher spatial and temporal resolution (~ 0.5 GtC yr^{-1}, Rödenbeck *et al.*, 2003). Because of poor observation station coverage, the fluxes in the tropical region are not well defined. The lower net flux estimates in the tropics are difficult to reconcile with large emissions from land-use changes, as they would imply excessive uptake rates in the intact terrestrial biosphere. On the other hand, although controversial, large uptake estimates have been reported from *in situ* biomass increment measurements (Phillips *et al.*, 1998).

Even though the top-down method does not clearly define the long-term source-sink pattern of CO_2 sources and sinks, it can capture the temporal variability reasonably well. The inversion studies confirm the role of the terrestrial fluxes dominating the interannual variability, in particular in the tropics. There is also substantial evidence that a significant fraction of the interannual variability is caused by fires (Langenfelds *et al.*, 2002), which is nicely captured by the top-down inversions (Rödenbeck *et al.*, 2003).

Carbon Cycle–Climate Feedbacks: Model Simulations of the 21st Century

A quantitative assessment of the various feedbacks between the carbon cycle and the climate necessitates the use of global coupled carbon cycle–climate models (C4Ms). Such models essentially represent the carbon cycle processes (Plate 2) embedded in a three-dimensional coupled atmosphere–ocean general circulation climate model. A pioneering study of this kind has been performed by Cox *et al*. (2000) with the Hadley Centre CCCM (HadCM3LC), which demonstrated a strong positive feedback. A comparison of this simulation with 10 similar C4Ms is provided by the coupled carbon cycle climate model intercomparison project (C4MIP, Friedlingstein *et al*., 2006). All models have been run following the same protocol by prescribing historical global emissions from fossil fuels and land-use changes extended until the year 2100 following the SRES-A2 emission projection (TAR; IPCC, 2001). Changes in future land use and management are not yet incorporated in the models. The protocol specifies a fully coupled simulation as well as an uncoupled simulation in which the climate feedbacks to the carbon cycle components are suppressed. Comparing these two simulations permits the assessment of the carbon cycle–climate feedback.

All C4Ms exhibit a positive carbon cycle–climate feedback, i.e. the simulated climate change reduces the carbon sinks in the ocean and on land. This in turn leads to a stronger build up of the atmospheric CO_2 concentration, thus enhancing the climate perturbation. A feedback analysis performed by Friedlingstein *et al*. (2006) shows that the gain of the carbon cycle–climate feedback loop, i.e. the enhancement of the climate response due to the feedback, is between 5% and 31%, with all models but HadCM3LC lying below 20%.

The comparison shows that the climate feedbacks on the terrestrial carbon sinks are stronger than on the ocean, but they also vary more strongly among the models. All models predict substantial uptake reductions on land in the tropics and modest or even small increases in the uptake in northern extra-tropical regions. The carbon fluxes from two exemplary model simulations (MPI, Raddatz *et al*., 2006; HadCM3LC, Cox *et al*., 2000) are shown in Fig. 3.2 in terms of simulated net primary production (NPP) and net ecosystem production (NEP) for the tropics and the northern extra-tropical region (north of 30°N). In the coupled and especially in the uncoupled mode both models show substantial increases in NPP due to the CO_2 fertilization effect as represented in the models. The relative increase of NPP with respect to the relative increase in the CO_2 concentration (often termed ‘β factor’) goes up to 0.6 for the HadCM3LC model. Such large CO_2 stimulations are not confirmed by current vegetation manipulation experiments, which, albeit, have been conducted for a limited duration. Both models show the expected different climate response of NPP in the two regions: in the northern extra-tropics NPP increases because of a lengthening of the growing season in a warming world. Conversly, in the tropics, drying and increases in temperature tend to decrease NPP, especially in the HadCM3LC model. The effect on the terrestrial carbon uptake is a strong decrease in the tropics, in the HadCM3LC model even turning to a source in the later half of this century due to climate shifts and drying of critical tropical forest

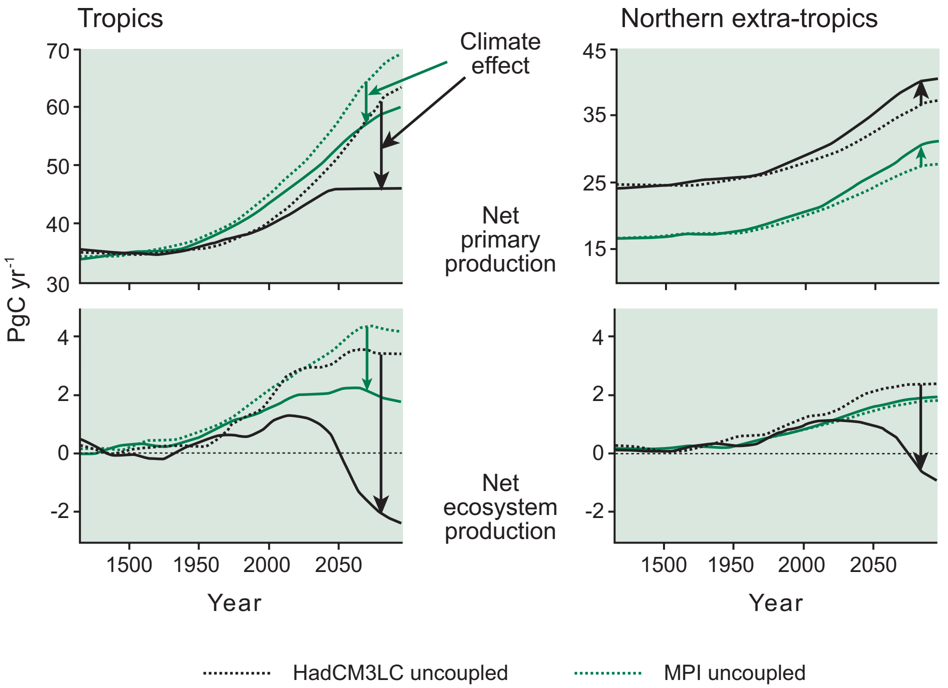

Fig. 3.2. Regional responses of the terrestrial carbon sinks as modelled by two exemplary carbon cycle–climate models from the C4MIP model intercomparison project (Friedlingstein *et al*., 2006). Dotted lines: uncoupled, solid lines: coupled simulation. Green lines: MPI model (Raddatz *et al*., 2007); black lines: HadCM3LC model (Cox *et al*., 2000). All time series have been smoothed with a low-pass filter in order to suppress the modelled interannual variations.

areas, in particular the Amazon. In the northern extra-tropics the effect is smaller and in the MPI model increases in respiration almost balance the increases in NPP. This summary picture is of course more complex when analysed regionally in more detail.

The present coupled carbon cycle–climate simulation experiments clearly do not allow a complete assessment of the multitude of possible carbon cycle–climate feedback processes. The simulations do not include the crucial effects of land use and land management, which will definitely limit the carbon storage potential of terrestrial systems. They also do not include the effects of other limiting factors, such as nitrogen (Hungate *et al*., 2003). Furthermore, critical carbon stores on land, such as wetlands and permafrost, are not simulated. Practically all these factors point to a more vulnerable terrestrial carbon cycle than represented in the present models. A strong positive climate feedback on the terrestrial carbon cycle also implies substantial higher emission reductions in order to stabilize the atmospheric CO_2 concentration than heretofore assumed in uncoupled stabilization calculations (Jones *et al*., 2006).

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4

Global Forest Sector: Trends, Threats and Opportunities

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Introduction

According to the UN Food and Agriculture Organization's *Global Forest Resources Assessment 2005* (FAO, 2005), forests cover 30% of the planet's total land area but they are diminishing: about 13 million ha – an area larger than Greece – are deforested per year. This is only partly compensated for by the 6 million ha of new forests established annually. Most of the deforestation takes place in developing countries and in the tropics.

Roughly half of the world's forests are located in the tropics and subtropics, half in temperate and boreal regions. Half of the forests are in developing countries, half in developed countries. About half of the forests are designated for production, and 60% of the wood harvested goes to industrial use, the rest goes mainly to fuelwood. However, in some leading forest industry countries a substantial amount of the wood that originally goes to industrial consumption is used for energy production as an industrial residue, thus increasing the share of energy use.

Forest-based industries are globally dominated by small and medium-sized enterprises: in the EU area over 90% of firms have less than 20 employees (Hazley, 2000). Although companies have merged during recent decades, the top 10 firms still cover less than 30% of the world's pulp and paper production.

Trends

There are several major trends that affect the future of the forest sector. *Globalization* is the most important driving force behind these trends. Globalization means that comparative advantages of different regions and countries (e.g. Ohlin, 1967) have become more and more central in determining the location of the production site.

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Production costs are the most important component of the comparative advantages in the forest sector. For example, costs of producing hardwood pulp are less than half in the best mills in South America and Asia compared with mills in Nordic countries (Häggblom, 2006a). Because wood raw material costs represent an essential cost factor in making pulp, a shift in the area for growing industrial timber from boreal and temperate forests to fast growing tropical and subtropical forests had already started in the 1980s and has accelerated in recent years.

The share of plantations used in production of industrial roundwood was 5% in 1960, 30% in 2005, and it is estimated that it will be 75% by 2050 (Sohngen *et al.*, 1999). The plantations represent only a very small share of the global forest area. Intensity of management varies but if all industrial wood came from effectively managed planted forests some 73 million ha, i.e. only less than 2% of the world's forest area, would be enough to satisfy the current global need of industrial wood. In 2020 the corresponding area would be 85 million ha (Häggblom, 2006b).

In line with the shift in timber growing there is also a shift in the consumption and production of forest industry products. Recent predictions (e.g. Suhonen, 2006) show that demand for current forest industry products will grow less than previously in OECD countries while at the same time, the demand will continue to increase considerably in many developing and transition countries. This means a shift in consumption of forest products from Western Europe, North America and Japan to the rest of Asia, Eastern Europe and Russia.

Real prices of wood-based products will continue to decline because of competition and improving productivity. The increasing competition between producers in different regions, and the geographical shift in demand, are gradually leading to a relocation of not only timber production but also the processing industry from north to east and south where it is closer to growing markets. It has been forecast (Suhonen, 2006) that during the next 15 years the growth of paper and board production will be lowest in North America and Japan, and highest in China and the rest of Asia.

Because the demand trend for industrial wood is levelling off in industrialized countries, the gap between the actual harvest and the harvest potential is likely to widen in these countries. It will mean an increase in growing stock in developed countries in contrast with many developing countries where forests will continue to disappear. This vision may not fully materialize in industrial countries if demand for wood for energy production rises considerably. However, initially, the additional wood energy will be derived mainly from harvesting and other residues (Seppälä, 2006).

Forces external to the forest sector, both international and national, will increasingly drive the sector. Although different dimensions of sustainability are ever more interlinked, especially in developed countries, environmental and social sustainability seem to be replacing economic sustainability as a major driving force. This will support the march of non-wood production and intangible products, such as recreation, conservation and other services (Seppälä, 2006).

Threats

The most visible and alarming global threat in the forest sector is *deforestation*. Among other negative effects, such as loss of biodiversity, it has a direct impact on global greenhouse gas emissions. Estimates vary but according to FAO (2006) 25–30% of the greenhouse gases released into the atmosphere are caused by deforestation. On the other hand, global warming will have a major impact on the forest sector, e.g. by changing the growing conditions of trees.

The most recent global forest resource assessment concludes that the rate of forest degradation appears to be decreasing slightly (FAO, 2005). Africa and South America suffer the largest net loss of forests. In contrast to this, the forest area in Europe is expanding. Asia had net losses in the 1990s but experienced a net gain in its forests in the period 2000–2005, primarily due to large-scale afforestation in China. Also in many other countries where there is deforestation, forest planting and natural expansion of forests have improved the situation by reducing the net loss of forest area (FAO, 2005).

Some experts (Kauppi *et al*., 2006) suggest that an end to deforestation might be in view. It is true that the forest area and forest biomass have increased in industrialized countries and some developing countries have expanded the area of their planted forests. However, information is still insufficient for any firm conclusions because adequate monitoring of forest resources is lacking in most countries. Therefore, claims that there is a rapid forest transition at a global scale can so far be considered only speculative although some countries have set encouraging examples.

Despite notable efforts towards international forest policy development and policy coordination, deforestation, forest degradation and loss of biodiversity continue. Among the other threats to a healthy forest sector are *illegal logging* and associated trade in forest products. These are problems especially in developing countries and economies in transition. Almost one quarter of hardwood lumber and 30% of hardwood plywood traded globally are of suspicious origin (Seneca Creek Associates *et al*., 2004). Corruption is often closely linked with illegal logging.

Until recently, a general belief has been that electronic solutions will not replace paper. This is based on a long-term trend in which the per-capita consumption of paper products is directly and positively related to the per-capita income and negatively related to the price of paper products. Recent studies (e.g. Hetemäki, 2005) have started to question this assumption. It seems apparent that *information and communication technology (ICT)* has begun to influence paper consumption but the impacts differ between various paper grades and across countries. For example, newsprint consumption in the USA has declined since 1987. This structural break in the US newsprint market is of historical significance. In recent years, some other high-income countries have followed the US trend, although in countries like China consumption is growing rapidly. There are signs that a structural break will also happen for other communication paper grades (Hetemäki, 2006) creating an additional major threat to the forest sectors in the OECD countries.

Opportunities

The global forest sector enjoyed a political renaissance in the early 1990s, mainly as a consequence of the Rio Earth Summit, where world leaders paid considerable attention to forests and international forest policy. In the late 1990s the high-level political attention shifted away from forests to address other concerns, such as poverty alleviation and food security (Maini, 2004). The diminished political status of the forest sector and, consequently, reduced allocation of public funds to its activities have been visible in many countries.

Now it looks as if forest-related issues again have a chance to become part of the high-level political agenda. The main reasons for this are *climate change* and *bioenergy*. Curbing deforestation is a cost-effective means of combating climate change by reducing greenhouse gases. For example, the recent *Stern Review* (Stern, 2006) highlights the role of deforestation as a major source of greenhouse gases, and also emphasizes the importance of the forest sector in producing substitutes for products made from non-renewable resources. Among these, biofuels and other wood-based energy products have now become hot topics in many countries, creating an opportunity for the forest sector.

The decreasing growth or possibly even a decline in the demand for many traditional forest industry products, such as newsprint, is already shaking the forest industry in some OECD countries. In order to survive and prosper, the forest sectors of these countries need new products and new business opportunities. The industry has to convert pulp mills to *biorefineries* whose outputs are not only traditional forest industry products, but also bioenergy products, wood chemistry products, as well as ingredients for medicines and functional food products (Seppälä, 2006). The cellulose-based biorefineries hold much greater potential for bioenergy production than do corn ethanol or soybean-oil biodiesel (Cole, 2006).

Although the most important economic function of forests is still their role as a source of timber supply, forests also provide a wide range of *non-wood products*, such as foliage, mushrooms, berries, honey and game. Billions of people rely on traditional medicines harvested from forests. These non-wood products have an economic potential that has been only partially utilized. Forests maintain much of the water supply, and trees make a contribution to water management and hence reduce the threat of flooding and erosion. Forests produce *services* in the fields of biodiversity and carbon sequestration. Forests are increasingly a source of recreation, health, tourism and aesthetic values. All these provide new opportunities for the forest sector.

In order to benefit from new opportunities the forest sector has to learn how to justify and quantify the economic value of the services of forests to obtain recompense. The *Stern Review* recommends that the international community should provide compensation for those who use forests for carbon sequestration by taking account of the opportunity costs of alternative land use (e.g. growing wood for industrial use). Some examples already exist: the New Zealand government recently gave the green light to farm carbon credits by growing forest sinks. A 10 000 ha development is the start of a proposed planting of 40 000 to 50 000 ha of trees for carbon farming (Gregory, 2006).

Payments for environmental services (PES) that forests can provide are not only connected with carbon sequestration. These PES schemes can also be used to pay, for example for biodiversity, landscape (aesthetics/ecotourism) and hydrological protection. For the time being, most existing PES are found in developed countries, and the majority of these are state run (Wunder, 2005).

Converting Threats to Opportunities

The global forest sector and forest sectors in many individual countries are experiencing a major change. Although deforestation continues in developing countries, having a significant impact on global emissions, many developing countries and countries in transition are gradually assuming the current role of the OECD countries as principal producers of timber and forest industry products. The shift of the growth of production of industrial timber and traditional forest industry products to new regions calls for novel products and new business opportunities from the industry in the OECD countries.

Many of the problems and threats to the forest sector originate from conflicts with other sectors (Seppälä, 2006). For example, tree plantations are often established on land formerly used by farmers and, simultaneously, forest areas are converted to agricultural land. Waterside vegetation is sometimes destroyed by logging, causing problems to fish populations. In tropical and boreal old-growth forests especially, timber harvesting decreases biodiversity. Forestry activities change the landscape and thus cause harm to tourism and recreation. In many countries there are problems between forestry and local indigenous communities over the control of the forest land used by these communities. These conflicts could often be avoided by ensuring better integration between all parties concerned (Mery *et al*., 2005). Forests are not just a resource to be exploited but they should also be seen as part of the human and natural landscape. This should lead to an integrated and more holistic management and use of forests and land, which means that policies for agriculture, forestry and other land uses should be consistent and mutually supportive. Promoting the holistic view is also a good means for the forest sector to make its activities and operations more acceptable to society.

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5

Carbon Sequestration as a Forestry Opportunity in a Changing Climate

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Introduction

It is now widely accepted that anthropogenic climate change will create one of the major problems facing mankind. The recent report by Stern (2006) overwhelmingly strengthened this view. It is also widely recognized that, while such climate change will affect the distribution and structure of forests in many parts of the world, the wise management of existing forests, reduced deforestation and the establishment of new forests offer three of the most effective, sustainable and productive approaches to coping with environmental change.

Contributions of Trees and Forests to Sustainable Development

Throughout the world, timber and reconstituted wood (pulp, paper, board) are major economic products with demand increasing dramatically as China and India industrialize; in the UK wood and wood products are the sixth largest import (£2.6 billion annually) providing a major opportunity for growers. In developing countries more than 55% of all wood cut deliberately is used for fuels (with or without formal market valuation). Additionally forests and trees play a major role in sociocultural and socioeconomic welfare, producing human and animal food, nutriceuticals and pharmaceuticals. Forests also act as land banks for agriculture; there is increasing pressure for reforestation to restore degraded land into agricultural productivity. The added value of forested land is an economic contribution in its own right. Forests provide employment and income while reducing risk in agricultural enterprises.

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There is now considerable debate and demand for research on the often-quoted beneficial impacts of trees and forests on local and global environments: soil conservation and improvement; water quality and quantity; flood control; climate and weather amelioration; shade and wind protection; site restoration; and biodiversity conservation for ecosystem function and stability. Recently, intense attention has been devoted to creating a monetary value for these formerly non-marketable services (e.g. Scherr *et al*., 2004); carbon sequestration and storage will expand throughout the century and may offer a major contribution to the reduction of carbon in the atmosphere.

Approaches to Carbon Reduction and Coping with Change

There are two basic approaches to reducing carbon dioxide (CO_2) in the atmosphere: (1) reduction at source and (2) capture (sequestration) and storage. In addition, we will require adaptation of plants, animals and human life styles to the expected changes.

Forestry is only one approach in a portfolio of solutions but existing technologies and infrastructures permit immediate action. Emissions from all industries, transport and domestic uses can be reduced by increased efficiency, cleaner technologies and conservative use.

Emissions will also be reduced by using renewable energy sources including wind, marine waves and tides, river and stream power, solar photovoltaic, biogas and biomass. Energy-related research and development activities are increasingly expected to be conducted by the industrial sector rather than government to create strong markets. There are significant opportunities for research and development of forest energy plantations such as the coppiced willow already in use in England and Scandinavia and *Jatropha* in some developing countries (Fitzgerald, 2006).

In the land use and forestry sector, carbon management is a function of biomass accumulation and storage. Therefore, any activity or management practice that changes the biomass in an area has an effect on its capacity to sequester or store carbon. A variety of forest management practices can be used to reduce the accumulation of greenhouse gases in the atmosphere by increasing the accumulation of carbon and by preventing or reducing the rate of release of carbon already fixed.

Provided it does not cause deforestation elsewhere, any activity that involves tree-planting results in the creation of new carbon sinks, e.g. carbon fixation during tree growth in afforestation, reforestation, forest rehabilitation or agroforestry schemes. Since substantial amounts of carbon (150–350 t per hectare) are stored in soils (Watson *et al.*, 2000), management practices that promote an increase in soil organic matter can also have a positive carbon sequestering effect.

In principle, forest conservation can serve as an efficient carbon offset. Deforestation of 13 million ha annually worldwide releases about 1.6 Gt of carbon (GtC) (IPCC, 2001; Houghton, 2005), accounting for up to 25% of global GHG emissions. In Brazil alone, approximately 2 million ha of forests are lost every year.

Despite substantial losses in overall forest cover, remaining primary forests, both tropical and temperate, represent huge pools of sequestered carbon, equating to 283 GtC (FAO, 2006). A large proportion of land under forest cover is threatened with conversion to other land uses that have lower values as carbon sinks. Avoidance and mitigation of carbon releases from these pools provide the quickest, forestry-based opportunity to slow the accumulation of CO_2 in the atmosphere. This is beginning to be recognized by voluntary carbon markets and may be a central additional mitigation mechanism in an international post-Kyoto regime.

Reducing emissions from deforestation can be direct or indirect. Direct interventions essentially require the ‘locking up’ of threatened land resources into protected areas. Indirect interventions comprise a far wider range of possibilities, including:

- increasing agricultural productivity (thus lowering the need for cyclical slash and burn cropping);
- development of agroforestry to meet fuelwood and other socioeconomic needs;
- opening of markets for indigenous forest products;
- recycling of wood waste and paper.

Avoiding deforestation can be complex and controversial as it is related to social and economic aspects of land use in a particular region. Often, government policies induce pressure on standing forests by specifically encouraging forest utilization. Some countries consider externally promoted conservation an affront against a nation’s sovereignty.

Important interventions that reduce carbon emissions from forestry practices include the introduction of reduced impact logging (Dykstra, 1997; FAO, 2006); this is attractive because approximately half the eventual greenhouse gains are realized over the first few years and are basically irreversible, yet forests continue to provide timber-based economic benefits. This also safeguards biological diversity and soil integrity and lessens the risk of failure for carbon offset investments.

Suppression of forest fires provides an obvious reduction in carbon emissions. Along with the crucial need to address the policy causes, a combination of practices of fire prevention and control, and available remote sensing monitoring systems, has great potential for reducing the frequency and extent of forest fires.

Finally, forestry can prevent release of carbon from fossil fuels elsewhere, through biofuel generation or material substitution. Sustainably harvested fuelwood can replace fossil fuels, and wood-based products can be used to replace materials that require high levels of energy and/or fossil fuels for their production, e.g. steel, cement, plastics.

In summary, forestry-based carbon offset projects can be based on two different approaches:

1. Active absorption (carbon fixation, sink creation, sink enhancement) in new vegetation.
2. Avoided emissions (sink or pool protection, compensated emissions reduction) from existing vegetation.

The first includes any planting of new trees (afforestation, reforestation and agroforestry) or increasing growth rates of existing forest stands (silvicultural practices). The second can be accomplished through prevention or reduction of deforestation and land-use change (e.g. conservation projects), and reduction in damage to existing forests (e.g. uncontrolled logging, fire). All methods have similar results in that they reduce the accumulation of greenhouse gases (GHGs) in the atmosphere but will require different analytical tools for the evaluation of their merits as carbon offsets (i.e. whether they differ from an ongoing baseline). Introducing avoided deforestation as an offset option in future climate regimes and carbon markets, as suggested by the Compensated Reduction proposal (Santilli *et al*., 2003), will increase the supply of carbon credits, maintain affordable costs of mitigation and encourage a substantial contribution of developing countries to GHG reduction efforts. The methods also differ in their other benefits related to biodiversity, hydrological and soil services.

Even if these approaches are taken up immediately, some adaptation to change will be essential. Forestry will require new species for some sites and new populations for others. Silviculturists and geneticists have long recognized the need for the evaluation and conservation of genetic variation between and within species and populations (Burley, 2004); most breeding strategies narrow genetic variation for productive characteristics but they include conservation populations to maintain variation in adaptive and productive traits in preparation for changes in site, environment, management and use. The current emphasis in developed countries is on restoring natural forests or establishing plantations using only local, currently adapted populations of indigenous species; this may be risky in view of the environmental changes predicted to occur during a tree's lifetime. Significant opportunities are available for the development of genetically improved material and technologies for mass propagation (Burdon, 2004).

Regulations and Markets

In December 1997, 170 countries agreed to sign the Kyoto Protocol during the third Conference of Parties (COP3) of the United Nations Framework Convention for Climate Change (UNFCCC). The most important aspect of the Protocol is the adoption of binding commitments by 37 developed countries and economies in transition (collectively called the Annex 1 countries) to reduce their GHG emissions by an average of 5.2% below the emissions of the year 1990 until the years 2008–2012. The Protocol allows the use of the following three 'flexibility mechanisms' for facilitating the achievement of these GHG emission reduction targets (UNFCCC,1998):

- *Emissions trading*: allowing the international transfer of assigned amount units (AAUs) between countries.
- *Joint implementation* (JI): the creation of emissions reduction units (ERUs) through projects developed in industrialized countries (Annex 1). In the case of forestry projects in JI, these are referred to as RMUs (removal units).

- The *Clean Development Mechanism* (CDM): a new mechanism resembling JI, which allows for the creation of Certified Emission Reduction (CER) credits from sustainable development projects that reduce emissions in developing countries, and regulated by the CDM Executive Board.

All of these forms of credit are expressed as tonnes of carbon dioxide (tCO_2) equivalent corresponding to avoided emissions. The mechanisms are predicated on the trading of credits between Parties to the Protocol and market participants, with a view to exploring the comparative advantages of different parties in achieving emission reductions in different locations. This market is now very active and it is estimated to reach €30 billion by 2012. In the UK, many companies in this sector have listed in the stock market to capitalize themselves for participating in this market. As an example, EcoSecurities Group Plc, based in Oxford, UK, is at the forefront of this market, with more than 350 emission reduction projects worldwide and the largest carbon credit portfolio in the world (more than 150 million CERs). The World Bank's BioCarbon Fund is the most significant investor in Kyoto-oriented forestry carbon projects to date.

The only forestry activities authorized to receive credits under the CDM are afforestation and reforestation of lands that have not supported forests since 1990. In spite of their huge potential to reduce emissions, projects based on avoided deforestation are not yet eligible for participation in the CDM, although a new mechanism for avoided deforestation is currently being considered by the Kyoto Parties. Furthermore, for currently eligible land-use activities, special carbon accounting provisions were put in place to create a tool for dealing with the temporary nature of carbon storage in biomass. This was achieved by adopting the concept of 'temporary CERs' (tCERs), in which projects receive credits that need to be replaced or renewed after 5 years, depending on whether carbon storage continues to occur (UNFCCC, 2001).

In turn, the objectives established by the Climate Convention have to be translated into national rules, regulations and legislation. In Europe this took the shape of the European Union Emissions Trading Scheme (EU ETS, January 2005) and National Allocation Plans, which break down emission reduction obligations to industries in individual countries. The EU ETS is a cap-and-trade system based on the allocation of limited amounts of emission rights (EU Allowances – EUAs) and the associated flexibility to buy or sell surplus allowances from other parties.

Within the UK, the Government's Energy White Paper (Department of Trade and Industry, 2003) aims to achieve 10% of electricity generation based on renewable sources by 2010 and 20% by 2020. The Renewables Obligation (established in 2002) and the Non-fossil Fuel Orders require 106 MW of a national total of 1185 MW to originate from biomass; these offer great opportunities to commercialize the growing, harvesting and processing of biomass for energy (e.g. Biojoule in Climate Care, Oxford, UK).

In addition to these legally regulated schemes, a large number of voluntary schemes are emerging whereby carbon emissions by organizations or individuals are offset by projects such as tree planting, the development of renewable energy resources, or other activities reducing emissions. The voluntary market is comparatively immature, highly fragmented and less clearly regulated. It currently represents a small fraction of Kyoto carbon markets but it is predicted to grow rapidly (World Bank, 2005).

Objectives of Business

Multinational, national and joint-venture companies seek financial profits for their owners and shareholders. The products, marketable services, fees and credits referred to above are valid targets for income generation by forestry and energy generating companies. However, they must be subject to socially and environmentally ethical behaviour related to traditional resource use rights, land acquisition, tenure, management and use.

Plantations are frequently managed by government departments but also by large, often multinational, companies, sometimes involving local people as outgrowers supplying central processing factories. Typical plantations are concerned largely with producing wood for saw timber or pulp/paper, frequently with exotic, fast-growing species such as tropical pines and eucalypts, again with some outgrower schemes and a mixture of export and local market objectives. With the development of methods for the valuation of social and environmental benefits derived from forests, there are growing opportunities for governments, commercial companies and local communities to capture them and profit financially from wise forest management and the establishment of plantations and agroforests.

Carbon can be treated as a product with international market values; carbon sequestration can be considered as one method of waste disposal and management with rights to generate income. International, national and voluntary schemes of carbon taxes and credits offer such sources of income. Companies such as C-Questor seek close integration of forestry with other activities directed towards coastal and desert development, land rehabilitation, forest restoration, water production and the generation of renewable energy sources. It is important to assess the interactions and leakages among these and ensure equitable distribution of benefits with ethical, sustainable management to avoid a currently voiced criticism of ‘the carbon scam’.

Business enterprises will earn income from managing the projects themselves, by designing, certifying and monitoring the validity and management of such projects for carbon finance, as well as purchasing and selling carbon credits. We are on the brink of a new market with growing willingness to pay for ecosystem services from old and new forests. The roles of forests in the maintenance of rainfall, provision of water and buffering regional weather conditions underpin energy, food and environmental security in many countries. The finance, energy, agricultural and insurance sectors may become major purchasers of these values added to forests. Clearly the captured value of these must exceed the opportunity costs from alternative land uses and there is a continuing need for research on the technical relationships, policy, forest management, energy production and conversion, and rural socioeconomics. Conversely the costs of meeting Kyoto Protocol obligations through forestry activities must also be evaluated by major emitters. In addition, the shadow value of alternative fuels systems will make small-scale technologies attractive for individual and community self-sufficiency.

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6

Forests and Climate Change: Global Understandings and Possible Responses

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Introduction

This chapter gives a global perspective on the relationship between forests and climate change. The international policy environment for forestry and for climate are outlined. Policy proposals to mitigate climate change through improved forest management, in particular by reducing deforestation, are discussed, with attention to how they can be integrated with wider climate policies. Adaptive forest management is also required to plan for expected and likely climate change.

Climate Change

Scientific research has established beyond reasonable doubt that global warming is already happening (IPCC, 2007). The previously fairly stable average global temperature is now rising by 0.2°C per decade (Hansen *et al.*, 2006) and increasing greenhouse gas (GHG) concentrations will raise the temperature further. Without policies to restrain anthropogenic emissions, the global average temperature is likely to increase by a further 1.1–6.4°C by 2100 (IPCC, 2007).

Forests are vitally important for the global carbon cycle. The total carbon content of forest ecosystems is of the order of 1200 gigatonnes (Gt), which represents most of the global terrestrial carbon and is more than the amount of carbon (550 Gt) in the atmosphere (IPCC, 2001).

Forests and Climate Change

Forests and climate change are intimately connected because these ecosystems affect climate through the absorption and accumulation of carbon in wood,

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(eds P.H. Freer-Smith, M.S.J. Broadmeadow and J.M. Lynch)

leaves and soil. When forests are burned or during forest clearance and harvesting, carbon is released into the atmosphere. Forest conversion contributes around 20% of annual CO_2 emissions; and over the past 150 years forest conversion has contributed an estimated 30% to the atmospheric build-up of CO_2 (IPCC, 2001a). Deforestation has a twofold impact on the carbon cycle, through loss of photosynthetic capacity and through the release of carbon stocks that have accumulated in forest ecosystems and, importantly, carbon contained in soil organic matter (Apps *et al.*, 2006). Quantifying the role of forests as sources of carbon emissions and in their role as carbon sinks has become key to understanding the global carbon cycle (FAO, 2006).

Forest soils also play an important role in the global carbon cycle. It is estimated that as much as 75% of terrestrial carbon is stored in soils (Lal, 2005). The response of forest soils to increasing atmospheric CO_2 will therefore be significant for the future global carbon cycle. However, the impact of climate change on forest soils is complex and uncertain. One of the main challenges to understanding carbon dynamics in forest soils lies in the length of the forest growth cycle. Another key challenge for research is the accurate estimation of the magnitude of changes in soil carbon globally (Brown, 1999).

Global warming and associated climatic changes are altering habitats (Parmesan and Yohe, 2003) and greater changes will take place in the future. Recent research has examined the risks of climate-induced changes to key ecosystems during the 21st century and concluded high risk of forest loss is likely for southern Siberia, the Russian Far East, the interior of western Canada, eastern China, Central America and Amazonia. Forests were forecast to extend into parts of the Arctic and some present-day savannahs (Scholze *et al.*, 2006). Global climate models (GCMs) which incorporate a coupled carbon cycle predict that, globally, carbon uptake by soil and vegetation will diminish or reverse. However, they do not agree on the extent to which this will increase GHG concentrations and temperatures, or the extent of forest loss (Cox *et al.*, 2004; Zeng *et al.*, 2004). In turn, this increases uncertainty about the permanence of forests as carbon sinks, making it difficult to determine the likely effectiveness of attempts to sequester carbon in forests. The knowledge gaps in this area are cause for concern and should be regarded as a research priority.

Forests also play a role in the protection and provision of a number of water services, yet quantitative information on the provision of these services is rare. Although generalizations can be made, the impact of forests on water services will be determined by site (Calder, 1999). Understanding the interactions between forests and water will become increasingly important, not only as the climate changes, but also as the world's growing population increases water demands (Nisbet, 2002).

In the absence of other anthropogenic pressures, research published by the Secretariat of the Convention on Biological Diversity has shown that climatic changes by themselves, even with rapid increases in temperature, would not necessarily lead to mass extinctions (CBD, 2003). However, considerable other pressures do exist – human pressures have fragmented, degraded and altered forest ecosystems, and how species will adapt to a rapidly changing climate in a fragmented and human-dominated landscape is difficult to predict. Biome transitions may cause changes in the interactions between ecosystems and the biogeochemical cycles, which could bring about feedbacks that further affect regional and global climates (IPCC, 2002). In addition, the loss of biodiversity will not only affect the ability of ecosystems to adapt, but will also affect the provision of goods and services which will have serious socioeconomic consequences.

International Forestry Policy

The question of a permanent international legal framework on forests has been discussed in the three forestry fora set up since the Rio Earth Summit in 1992: the Intergovernmental Panel on Forests (IPF), Intergovernmental Forum on Forests (IFF) and United Nations Forum on Forests (UNFF), and remains divisive and contentious. Some parties argue that the current fragmented forestry regime has led to inefficiencies, gaps and duplication. Others argue that a global forests convention is unnecessary because it would only be able to legislate at a global level for global values and public goods such as climate, biodiversity and trade, which already have institutions governing them, i.e. the UN climate and biodiversity conventions and the World Trade Organization (WTO).

Despite the failure to reach consensus on a global forests convention, national policy makers recognize the need to conserve biodiversity, forest productivity and the long-term survival of forest communities (McDonald and Lane, 2004). There is also widespread acceptance of the importance of forests in the provision of ecosystem services (Daily *et al.*, 1997).

Since the adoption of the Forestry Principles at the Earth Summit in 1992, the concept of sustainable forest management (SFM) has dominated the international forestry discourse. SFM is based on the three pillars of sustainable development, and seeks to ensure forests are managed to optimize their social, economic and environmental benefits for both present and future generations. The capacity to adapt to climate change is also a necessary component of sustainability as identified in the Helsinkii Accord and SFM provides a framework into which adaptation to climate change can be integrated. The various international discussions on forestry have produced 270 proposals for action for SFM, which are now being taken forward by UNFF. For example, at UNFF in 2006 it was agreed to reverse the loss of forest cover worldwide; enhance forest-based benefits; increase the area of protected and sustainably managed forests; and reverse the decline in official development assistance for SFM (UNFF, 2006).

International Climate Policy and Forestry

The complexities of forest ecosystems has meant that, to date, deforestation has been largely excluded from major climate negotiations, despite the significant role that it plays in climate change.

Under the Kyoto Protocol, ‘carbon sinks’ refer to human-induced Land Use, Land-use Change and Forestry (LULUCF) activities, including afforestation, reforestation and deforestation. The Clean Development Mechanism (CDM) was designed to generate investment within developing countries, and to promote the transfer of environmentally friendly technologies (UNFCCC, 2005). The mechanism allows industrialized countries to offset their emissions by implementing sustainable development projects that reduce emissions in developing countries. Sink projects in the CDM are limited to afforestation and reforestation. The Kyoto Protocol also allows Annex I Parties to obtain credits for funding afforestation and reforestation activities in other Annex I countries (through Joint Implementation, JI). Conservation projects are explicitly excluded, because of concerns that protecting forest in one place would only lead to it being lost elsewhere (known as leakage) and that funding projects to prevent deforestation would swamp the market and replace emissions reduction activities (Goldberg and Silverthorne, 2002). By October 2006 no afforestation or reforestation projects had been registered by the CDM Executive Board, although one reforestation project was requesting registration and two more reforestation projects were under consideration (Stern, 2006).

Some have criticized the generation of carbon credits through afforestation because it is often associated with plantations, which have negative impacts on biodiversity in some locations (CBD, 2003). They frequently actually reduce soil carbon stocks compared to the previous land use (Guo and Gifford, 2002). Afforestation in inappropriate locations can also have negative impacts on water supplies (Calder *et al.*, 2004). Forest restoration and agroforestry in formerly forested areas are much less controversial approaches.

In discussions about the post-2012 climate regime Papua New Guinea has proposed that developing countries receive carbon credits for the amount they reduce the rate of deforestation below a baseline that could be sold on the international carbon market. Brazil has proposed an alternative scheme where tropical forest countries that reduced their emissions compared to a baseline would receive compensation from industrialized country governments based on the average value of carbon on the carbon markets (Moutinho *et al.*, 2005).

It is important to create financial incentives for developing countries to tackle deforestation, but there are some difficulties with selling credits on the carbon markets. Avoided deforestation may not keep carbon out of the atmosphere permanently and there is a danger that the credits for avoided deforestation would be too cheap and swamp the carbon market. Alternatives to inclusion in the carbon market, such as by maintaining a separate but complementary approach, offer the possibility of being more closely targeted on reducing deforestation and the issues associated with it. One possibility is specialized funds, along the lines proposed by Brazil, because there are few direct trade-offs with other forms of mitigation. Another possibility is separate markets for forest credits. These credits could recognize a wider range of benefits than just avoided emissions, including biodiversity. If the credits were not tradable on the carbon markets, emissions reductions need not be the denomination and it would not be necessary to look for parity with the global carbon price (Stern, 2006).

Forests and Climate Change Mitigation

In the past two decades alone, land use and land-use change activities are estimated to have led to net emissions of 1.7 ± 0.8 GtC yr^{-1} during the 1980s, and 1.6 ± 0.8 GtC yr^{-1} during the 1990s (IPCC, 2000). IPCC (2001b) identifies three strategies by which biological approaches can be used to curb the increase of atmospheric CO_2:

- *conservation:* conserving an existing carbon pool, thereby preventing emissions to the atmosphere;
- *sequestration:* increasing the size of existing carbon pools, thereby removing CO_2 from the atmosphere;
- *substitution:* substituting biological products for fossil fuels or energy intensive products, thereby reducing non-renewable CO_2 emissions.

Conservation

Of all the environmental challenges facing forest managers, it is the halting of deforestation that remains both the most pressing and the most difficult. Deforestation is estimated to result in the loss of 13 million hectares (ha) of forest per year (FAO, 2006), and has led to a total reduction in the global area of forests of almost 20% in the past 140 years. It contributes approximately 18% of global carbon emissions and is predicted to contribute a further 40 $GtCO_2$ between 2008 and 2012, unless urgent action is taken soon (Stern, 2006). Although the global loss of forest cover is decreasing, deforestation rates in the tropics continue at an alarming rate.

The main cause of deforestation is the clearing of forests and their conversion to pasture and cropland for agricultural use, although it may be exacerbated by a number of other factors, such as the building of access roads or a growth in the regional timber markets. Contrary to popular opinion, only a very small proportion of deforestation is the direct result of logging, although illegal logging is largely responsible for tropical deforestation in South-east Asia (Reid *et al.*, 2004).

The underlying drivers of deforestation are highly complex and include poverty, population growth, institutional failure, changes in economic policies and agricultural intensification. Oversimplification of the causes, or excessive focus or blame on one key factor such as poverty or population growth, mask a variety of interacting factors that are temporally, politically and spatially specific (Rudel, 2005). In order to successfully tackle deforestation, forest managers and policy makers need to be sensitive to this complexity.

A recent report published by the World Bank identifies two key policy challenges that forested countries face when attempting to halt deforestation: forest governance; and the determination of forest ownership and access rights (Chomitz *et al.*, 2006). In order to ensure forests are managed in a way that benefits all stakeholders, effective forest governance is essential. Enabling effective and equitable forest governance will become increasingly important as the impacts of climate change become apparent. Forest management strategies for mitigation and adaptation will only work if the necessary laws, policies and institutions are in place to enable their adoption. In turn, the regulations, policies and laws that determine how forests are managed will not succeed in achieving their objectives if they fail to reflect the values of society (Kimmins, 1997).

In addition, it is important that systems of land tenure and forest ownership are clearly and equitably assigned. Deciding on an appropriate system of forest governance depends on local circumstance and culture, and does not necessarily imply privatization of state-owned forests. Evidence suggests community rights and other informal institutions can be an equally effective means of governing forest resources. However, the attribution of property rights does not guarantee a landowner will conserve a forest. For example, if cut timber is worth more to a landowner than standing forest, there will be no incentive for them to protect the forest and deforestation is likely to occur, regardless of the wider impacts of this on society (Gibson *et al.*, 2002).

However, if the owner is paid for the wider services that the forest provides to the local and global community, for example the regulation of water flows in a catchment, the value of the preserved forest may outweigh the value of timber, preventing deforestation. Case study evidence suggests that recognizing the ecosystem services provided by forests and financially compensating landowners for the benefits of these is a particularly efficient way of preventing deforestation. The internalization of the cost of these additional services forms the premise of Payment for Ecosystem Services (PES) Schemes, which operate on the principle that the resource users and communities that provide an environmental service should be compensated for the cost of their provision by those that benefit from them (Mayrand and Paquin, 2004). PES Schemes have been pioneered in a number of countries, most successfully in Costa Rica, and are a promising approach to forest conservation.

Sequestration

The planting of trees is recognized as one long-term strategy for forest managers and policy makers seeking to mitigate climate change. However, afforestation and reforestation are no replacement for the protection of primary forests and, as such, afforestation schemes should be carried out with due consideration of the wider social and environmental impacts of these large-scale, and often intensive, schemes. In response to criticisms about the sustainability of large afforestation programmes for sequestration (for example, see Friends of the Earth International, 2000), there is mounting support for afforestation and forest management efforts that adopt a more holistic, sustainable approach to forest management. This approach seeks also to increase the local environmental services provided by forests, such as through land restoration projects and agroforestry. For such an approach to become widespread, it is likely that the transaction costs of small-scale projects funded through the CDM will need to be reduced.

Substitution

The substitution of forest biomass for energy intensive products or fossil fuels, through the use of timber and forest biomass as wood products or bioenergy, is the third major way in which the forestry sector can contribute to reduced carbon emissions.

Wood products are a renewable resource. The carbon they contain remains stored for the duration of the product's lifetime, until they decay or are burnt. The Intergovernmental Panel on Climate Change (IPCC, 2000) identify three ways in which wood products can be managed to increase carbon stocks:

- increasing the useful life of products;
- increasing product recycling;
- shifting the product mix to a greater proportion of wood products.

Life cycle assessments (LCAs) have shown that substituting traditional materials such as concrete or bricks with a similar amount of sawn timber can result in significant reductions in greenhouse gas emissions (Reid *et al.*, 2004). Certification may play a valuable role in ensuring that the timber is sustainably produced and not simply compounding the problem by acting as an additional driver for deforestation.

Three main sources of biomass fuel can be identified:

- forestry materials (fuel is a by-product of other forestry activities including harvesting residues and sawmill co-products);
- energy crops (e.g. short rotation coppice (SRC) willow or miscanthus, where the crop is grown specifically for the purpose of energy generation);
- agricultural residues (such as straw or chicken litter).

Bioenergy has the potential to play a role in reducing carbon emissions by substituting for fossil fuels. However, the avoided CO_2 emissions of any biomass energy system are not simply those that result from the substitution of fossil fuels for biomass, because fossil fuels may continue to be used elsewhere in the biomass system. It is therefore vital that when assessing the carbon-substitution potential of a biomass energy system, a full LCA is employed. There is also the risk that the need for land to meet demand for bioenergy will increase the pressures for deforestation or destruction of other habitats. The competition between crops for bioenergy and crops for food will mean the world's agricultural economy will face far greater demands (Brown, 2006).

Adaptive Forest Management

The initial response of the international policy community to the threat of climate change was to concentrate on mitigation. But with atmospheric CO_2 levels rapidly increasing and climate models predicting ever-greater threats of change, a new emphasis has begun to fall on adaptation. It is now clear that forest managers and policy makers will have to adapt to climate change if forests are to be resilient to the impacts of climate change.

Approaches to adaptive management are complex because not only is the climate changing, but the exact nature and extent of future changes is unknown. This means that forest managers will always have to consider a range of possible future climates and plan for all of them. They will have to pursue a mixed strategy in their choice of forest types, species and provenances, and maintain diverse approaches to gene pools and landscape management. This approach conflicts with current biodiversity policies, such as CBD and the EU Habitats Directive.

Care needs to be taken when judging the success of an adaptation project, to ensure that externalities and spillovers are not imposed on other actors (Adger *et al*., 2005). The key to successful adaptive management lies in balancing competing criteria and acknowledging when trade-offs are unavoidable or unacceptable.

Public Understanding of Forestry and Climate Change

Studies examining the public's understanding of forests and climate change suggest that, although sometimes misguided, public opinion would favour many of the adaptation and mitigation options currently available to the forestry community. There is a risk that by placing such a great importance on reducing deforestation, the public are likely to overlook other options and fail to acknowledge their own direct contributions to emissions and climate change.

Key Policy Objectives

The uncertainties surrounding the science of climate change, the complex ways in which forests and climate interact, and the long life cycles of forest ecosystems, mean that forest managers and policy makers seeking to accommodate climate change are faced with a very difficult task. Nevertheless, a number of key management objectives can be identified:

- Halting deforestation
- Reducing illegal logging
- Sequestration projects: although they should be treated with caution and not accepted as an alternative to the prevention of deforestation
- Reducing uncertainties
- Sustainable forest management.

There are a number of barriers that need to be overcome before these policy objectives can be met. To date, much of the climate change and forestry research has been focused on modelling and forecasting. However, this research faces considerable challenges because of uncertainties in the vulnerability of species and ecosystems and inadequate projections of the future climate at smaller spatial and temporal scales. In addition, adaptation to climate change will require changes in the ecological, social and economic systems. The development of these adaptation measures, under an unknown climate and in an unknown socioeconomic context, are also highly uncertain (Spittlehouse and Stewart, 2003).

One of the key challenges in international policy for climate change and for forests has been the different agendas of developed and developing countries. While developed countries have so far focused on preventing further emissions to the atmosphere, support for adaptation by developing countries has largely been piecemeal (Watkins, 2006). The question of a global forests convention also highlights this divide; while developed countries were largely concerned with forest conservation, developing countries focused on the sovereign rights of states to control and exploit their natural resources (Humphreys, 2003).

A further barrier comprises the current focus on large-scale projects that centre on financial net benefits rather than the wider social and environmental benefits. A short-term focus on quick financial returns has done little to ensure the inter-generational equity that is essential for sustainable forest management and long-term adaptation to climate change.

A final barrier comprises the international, regional and local policy conflicts. Most prominent of these are the conflicts between policies for adaptation to climate change and those that promote economic development. These conflicts need to be reconciled before real progress can be made.

Requirements for Achieving the Policy Objectives

In order for these policy objectives to be achieved, certain key requirements must be in place.

1. An accurate valuation of the environmental services that are provided by forest ecosystems is needed. This valuation should consider not only economic benefits but also the social and environmental benefits that are provided by forests and other ecosystems.
2. Decision-making processes must be participatory, involving all stakeholders. These processes must also be open and transparent, and should ensure that those responsible for making decisions are held accountable for them.
3. Policies need to be flexible and responsive in order to adapt to future climate changes.
4. Knowledge transfer partnerships need to be developed. Information sharing needs to be encouraged so that the forest community can learn from one another's experiences and strengthen the knowledge-base.
5. The wider policy objectives, such as poverty eradication and assisting developing nations to adapt to climate change, must be considered.

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7

The Forest Science–Policy Interface

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Introduction

This chapter focuses on policy with regard to consideration of the carbon (C) in the terrestrial biosphere, particularly forests and their soils, and climate change. The Intergovernmental Panel on Climate Change (IPCC) has provided a structure by which science has presented evidence to the negotiations of the UN Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol. The UNFCCC sets out a framework for action aiming to stabilize atmospheric concentrations of greenhouse gases (GHGs) to avoid 'dangerous anthropogenic interference' with the climate system. Controlled gases include methane (CH_4), nitrous oxide (N_2O) and, in particular, carbon dioxide (CO_2). The UNFCCC came into force in March 1994 and now has 189 Parties. In December 1997 at the Third Conference of the Parties (COP3) in Kyoto, Japan, delegates adopted a Protocol which commits developed countries and countries making the transition to a market economy to emission reductions. These countries, known under the UNFCCC as Annex I Parties, agreed to reduce overall emissions of six greenhouse gases by an average of 5.2% below 1990 levels between 2008 and 2012 (the first commitment period), with specific targets varying from country to country. (The number of gases is actually larger since the expressions perfluorcarbon and hydrofluorcarbon designate more than one gas.)

The Kyoto Protocol also established three flexible mechanisms by which Annex I Parties could meet their national targets cost-effectively:

- an emissions trading scheme;
- joint implementation (JI) of emissions-reduction projects between Annex I Parties;
- the Clean Development Mechanism (CDM) which allows emissions reduction projects of Annex I Parties to be implemented in non-Annex 1 Parties (i.e. developing countries).

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After COP3, Parties began negotiating the rules and operational details of how countries will reduce emissions and measure their emission reductions. In total, 163 Parties have now ratified the Kyoto Protocol including 37 Annex I Parties representing 61.6% of Annex I greenhouse gas emissions in 1990. The Protocol came into force in February 2005.

Forests and the Carbon Cycle

The declared objectives of the UNFCCC, to stabilize atmospheric GHG concentrations in the atmosphere, can be considered against a background in which CO_2 is the most important GHG and there is a dynamic equilibrium between C in the atmosphere and C in the terrestrial biosphere. Photosynthesis and decomposition of organic matter transfer C in different directions. The timescale of these fluxes is critically important. The net increase in the amount of C in the atmosphere/biosphere system is the atmospheric input of C from fossil fuels less the ocean and geological removal. The C emissions from fossil fuel consumption, ocean C uptake and the ongoing increase of atmospheric C (CO_2) can be measured directly and thus are accurately known. The C emission caused by land-use change (principally deforestation) is usually calculated as the residual or remaining term and there may be compensating errors between this residual term and the value for terrestrial biosphere uptake. A significant degree of uncertainty comes from estimation of the area of land cleared in deforestation annually. This value is usually based on the FAO Global Forest Resources Assessment (GFRA) values which are based on a definition of forests rather than on a knowledge of carbon content. A survey conducted in Brazil suggests that tropical deforestation may account for as little as 9% in global emissions. This number is arrived at by using the FAO data to determine the fraction of the global rate of tropical deforestation that corresponds to Brazil (30%; FAO, 2005) and then scaling the emissions from land-use change in the national inventory of emissions of Brazil to the world by using the above fraction. These results are being prepared for publication. To achieve stabilization of C in the atmosphere the net input must be stabilized. Forests have an important role in this for two reasons: first, they represent a stock of C that is removed from the atmosphere and, secondly, they are a mechanism by which solar radiation can be converted into usable energy on a timescale much shorter than the geological timescale by which fossil fuels perform this conversion.

Considerations of Forestry in the UNFCCC and the Kyoto Protocol

Although the Kyoto Protocol contains a number of provisions on land use, land-use change and forestry, there has been little progress on actions to achieve the potential role of forests in stabilizing atmospheric C concentrations. These consultations have been one of the most contested, resulting in negotiations which have spanned a number of years. Much discussion has been centred on how to govern sequestration of C in trees, over how this could count towards developed countries' emissions reductions and of the rules and procedures for monitoring these credits. Following what has happened within the UNFCCC and Kyoto Protocol negotiations and the extent of implementation, the international policy debate is currently focused on the negotiation of a new mandate for a future international climate change regime. Now is thus a good time to raise the profile of the potential role which forest ecosystems can play.

The UNFCCC and Kyoto Protocol were negotiated at a time when the global carbon cycle was not fully understood. There were problems in the definitions of anthropogenic emissions by sources and of anthropogenic removal by sinks, and the breakdown of negotiations in 2000 stemmed from disagreements on carbon accounting in the Land Use, Land-use Change and Forestry (LULUCF) forum (Watson *et al.*, 2000). This led to the consideration of C stored by land use and land-use change as a means of decreasing the cost of meeting emission reductions targets which had already been agreed. National costs, in some circumstances, could conceivably become zero simply by claiming credit for management of land. The dangers are that countries might claim credit for the removal of C from the atmosphere which occurs in the portion of the terrestrial biosphere in their territory. If this approach/practice were to be accepted, countries could claim credit for the removal of about 2 gigatonnes of C per year (GtC yr^{-1}) and, if removal by the oceans was also considered, for a further 2 GtC yr^{-1}. The Kyoto emissions reductions would then be effectively meaningless. The consequences of these problems include: uncertainty about the role of deforestation; miscalculation of cost estimates of emission reductions; and questions of national sovereignty in international treaties which affect deforestation.

An attempt to solve these problems was made at COP6 with the suggestion that in accounting for removals the following should be factored out: the impacts of CO_2 fertilization, nitrogen deposition and the effect of age distribution from previous practices. An alternative approach is to undertake full carbon accounting.

Wood as a Renewable Energy Source

There is also a problem in the way that the Kyoto Protocol deals with wood as a renewable energy source substituting for fossil fuels or wood from a non-renewable origin. For Annex I countries where renewable biomass is used there are credits in the sense that the national C inventories will reflect the decrease of emissions. In non-Annex I (developing) countries this is not so because the CDM regulations only allow credits on a limited basis. Even though there is no regulation stating that the replacement of wood from native forests with wood from a renewable (planted) forest cannot earn CDM credits, there is a *de facto* interpretation of the rules that prevent such credit. The argument goes that such replacement tends to contribute to avoiding deforestation and, since avoided deforestation cannot be credited, the replacement is not acceptable as a CDM project. In Africa and South America native forest is still relied on as a fuel source to a very significant extent rather than fossil fuels, so that substitution of this type is not possible.

The Future

There is a problem that creating a protected area in a country or requesting that a given land area is left as forest cover (by international treaty) may be viewed as infringing upon the sovereignty of that country. However, it might be possible to invoke a convention to establish that countries agree to care for the portion of the stock of C in the terrestrial biosphere that is under their jurisdiction, in a full C accounting regime. Currently international negotiations are focused on how to avoid emissions from deforestation in developing countries. At the most recent meeting, in November 2006 in Nairobi, Kenya, delegates agreed to hold a workshop in 2007 to focus on ongoing and policy approaches and positive incentives, and technical and methodological requirements related to their implementation, assessment of results and their reliability, and improving understanding of reducing emissions from deforestation in developing countries. Furthermore there are currently important discussions within the UN Forum on Forests on how best to initiate and implement an international forestry agreement (see Badiozamani, Chapter 23).

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III

Forestry Options for Contributing to Climate Change Mitigation

> '... given that climate change is happening, measures to help people adapt to it are essential. And the less *mitigation* we do now, the greater the difficulty of continuing to adapt in future.'
>
> *The Stern Review: Executive Summary, November 2006*

This section discusses a wide range of forestry mechanisms for mitigation of climate change. These include:

- Reduction in deforestation
- Afforestation and reforestation
- Sustainable forest management
- Substitution (for fossil fuels and for products which are less carbon or energy efficient)
- Sequestration (in stands and soils)

8

Causes of Gaps Between Perceived Potentials and Actual Implementation of Forest-sector Mitigation Activities

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Introduction

Changes in the use and management of forest lands have long been recognized as possible means to mitigate greenhouse gas emissions through increasing carbon stocks, conserving carbon stocks or use of harvested biomass for wood products or energy (Marland and Marland, 1992; Brown *et al*., 2000b; Kauppi and Sedjo, 2001). Not only do the changes in use and management of forest lands have the potential to sequester and prevent emissions of significant quantities of carbon dioxide (CO_2), but they also provide multiple co-benefits. These other benefits include local environmental improvements (soil rehabilitation, biodiversity protection), social benefits for local communities (creation of revenues, transfer of knowledge and improved capacity to adapt to climate change) and engagement of the whole world in the fight against climate change.

Monitoring and measuring systems, accounting rules and models have been developed to quantify and assess the effectiveness of alternative mitigation options – often referred to as carbon sink activities (Brown, 2002; Brown and Masera, 2003; Schlamadinger *et al*., 2003; Pearson *et al*., 2005; Kurz and Apps, 2006). The need to perform such evaluations using systems analysis approaches with appropriately defined system boundaries has been recognized, but some challenges remain in the implementation of life cycle analyses and assessment of non-carbon climate impacts of alternative mitigation options.

A large gap remains, however, between the perceived biological and technical potentials of forest sector mitigation options and the actual implementation of such

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activities. An obvious question is: why is the implementation of such activities in the forest sector not occurring? An examination of the causes reveals a variety of reasons and large regional differences.

Why Implementation is Not Occurring

Markets for buying and selling carbon credits to help Annex 1 countries meet their targeted greenhouse gas emissions reductions are emerging. Although these markets are developing, very few of them include provisions for trading emissions reductions from forestry activities (such as afforestation or reforestation of degraded lands or reducing deforestation). For example, credits from Joint Implementation (JI) and the Clean Development Mechanism (CDM) forestry projects are excluded from the European Union Emission Trading Scheme (ETS) until at least 2008. In the non-Kyoto countries of USA and Australia there are, however, several registries or exchanges developing to facilitate trading of carbon sequestration credits, e.g. the California Climate Action Registry (www.climateregistry.org), the US-based Chicago Climate Exchange (www.chicagoclimatex.com/), and the Australian-based New South Wales GHG Abatement Scheme (www.greenhousegas.nsw.gov.au/). All of these registries and exchanges have detailed rules and guidelines for project developers to measure, account and report the carbon credits resulting from forestry activities.

Terrestrial carbon sequestration was a key topic in the many discussions and negotiations leading up to the Kyoto Protocol because it had been shown that carbon sink projects could play an important role at relatively low cost, especially in developing countries (Brown *et al*., 2000b; Kauppi and Sedjo, 2001). It was partially for this reason that the CDM evolved out of the Kyoto Protocol. Because of the expectations that sinks projects would be included as a mechanism for achieving targets, several pilot projects were voluntarily implemented in the 1990s under the Activities Implemented Jointly (AIJ) pilot phase (unfccc.int/program/coop/aij/aij_np.html). These AIJ projects involved mostly private sector entities, for example electric utility companies, oil companies and environmental non-government organizations (NGOs). Between the beginning of 1996 and the end of 2003, 76 transactions involving carbon sequestration in the Land Use, Land-use Change and Forestry (LULUCF) sector were signed, representing 40 million tonnes of CO_2 equivalents (tCO2*e*) (Bosquet, 2005; Lecocq, 2004). Relative to all of the carbon transactions that took place over the same period, sinks projects accounted for 21% of the total number and 23% of the total volume. In volume terms, carbon sequestration projects were the single largest project category, and more than three-quarters of this volume was transacted between 1996 and 1999. Between 2000 and 2003, the share of sinks projects in total volume transacted declined sharply. Although the share declined, 19 sink purchases were concluded in 2002 and another 20 in 2003.

An example of a large-scale transaction that took place during the 1990s is the Noel Kempff Climate Action Project in Bolivia (Brown *et al*., 2000a; nature.org/initiatives/climatechange/work/art4253.html). In 1996, the Government of Bolivia, the Bolivian conservation organization Fundación Amigos de la

Naturaleza (FAN), American Electric Power and The Nature Conservancy designed a forest-based pilot project to allow for the expansion of Noel Kempff Mercado National Park, now totalling approximately 1.5 million ha. PacifiCorp and BP Amoco joined the project in 1997. About US$9.5 million has been invested in this project that is expected to generate about 15 million tCO2*e* over 30 years from avoiding deforestation and from stopping logging. This project was certified in 2005 by SGS at the request of the Government of Bolivia.

Although not party to the Kyoto Protocol, efforts to implement climate change mitigation activities in various sectors, including the LULUCF sector, are ongoing in the USA, facilitated by voluntary GHG reduction registries, funded research programmes and initiatives for voluntary commitments to reduce emissions (Tuttle and Andrasko, 2005). These efforts are highly diverse, decentralized and often feature ‘learning by doing’; they also include a wide range of players including states, cities, private companies, forest-based trade associations, NGOs and federal agencies. For example, concerned about future regulations on GHG emissions, many electric utility companies in the USA, working with land trusts and federal agencies, are financing the planting of more than 30 000 ha of agricultural land along the Mississippi Valley with trees to restore the native bottomland forests (Tuttle and Andrasko, 2005; www.environmental-synergy.com/main.html).

The observed recent global decline in sinks projects is mainly caused by the lengthy and complex process of registering a CDM project with the CDM Executive Board (CDM-EB) (cdm.unfccc.int/Projects/pac/pac_ar.html) that involves more steps compared to conventional project cycles (UN Environment Program, Finance Initiative, 2005). As of October 2006, more than 30 potential project documents, including methodologies, have been submitted to the CDM Afforestation/Reforestation Working Group for review. Six methodologies for baselines and monitoring have been accepted that should speed up the process, resulting in increased registration of carbon sequestration projects.

Financing CDM-eligible carbon sequestration projects creates a challenge as there are many upfront costs, as with non-forestry projects, but significant carbon benefits generally take time to accrue because of the growth pattern of forests. One of the largest investors in carbon sequestration projects is the World Bank’s BioCarbon Fund (BioCF, carbonfinance.org/Router.cfm?Page=BioCF), a public/private initiative that was mobilized in May 2004 to focus solely on the LULUCF sector, including JI and CDM activities. Such activities could include afforestation of degraded lands, enrichment planting for forest restoration, community forestry, agroforestry and production of biomass fuels. The main objective of the BioCF is to test and demonstrate how LULUCF activities can generate high-quality emission reductions while creating environmental and livelihood benefits that can be measured, monitored and certified, and stand the test of time – that is a ‘learn by doing prototype fund’. A group of about 20 project candidates has been identified for the first phase of the fund, taking into account several criteria, including the likelihood of the project raising the necessary start-up capital, the price requested for a tCO2*e* (the BioCF will pay about US$3–4 per tCO2*e*), the developer’s track record, geographical and technological diversity, and the expected benefits for the local environment and communities.

Conclusions

This brief summary highlights some of the financial and institutional causes of the gaps between the perceived biological and technical potentials and the actual implementation of forest-sector, mitigation activities. Chapters 9–14, which make up the rest of this section, address forestry mitigation options from different angles and provide additional insights into the opportunities and constraints of implementing forest sector mitigation options.

Europe's forests, because of management history and current age-class structures, are expected to remain carbon sinks for the coming decades (Nabuurs, Chapter 13). Both climate change impacts and forest management choices will affect their sink strength but at present few incentives exist to alter management plans to address carbon sequestration objectives. Silvicultural options to increase carbon density and the magnitude of their benefit differ by regions across Europe.

Combustion of woody biomass residues has long been used to provide heat, and at times power, in the wood processing sector. Technological advances in the efficient conversion of woodfuels have been significant and, together with recent increases in energy prices, more bioenergy plants have become economically viable (Sims, Chapter 11). Despite sectoral success stories, several technical, economic and institutional hurdles need to be overcome before large-scale adaptation of woodfuel for energy will occur. Uncertainties regarding the accounting rules for international harvested wood products trade and the future 'ownership' of carbon emissions associated with the retirement of wood products and woodfuel use are issues whose resolution would facilitate greater implementation of forest sector mitigation activities (Matthews *et al.*, Chapter 12).

The opportunities for forest sector mitigation activities remain large but will require catalysts to encourage their implementation. Catalysts could include financial incentives, upfront financing (e.g. BioCF), government policies, and technological and capacity improvements to increase the economic viability of forest sector responses, including woodfuel technology.

An analysis of successfully implemented forest sector mitigation strategies in some countries and regions can identify the ecological, social and economic prerequisites that were required for the success of mitigation projects. The factors limiting successful implementation are typically not technical or scientific in nature but instead are economic, institutional and social constraints.

Although the forest sector can contribute to mitigation activities, the potential benefits of these activities can be diminished where climate change impacts such as increases in extreme events and natural disturbances cause decline or destruction of forests. The design of successful forest sector mitigation portfolios should therefore take into consideration both mitigation and adaptation objectives.

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9

Forests Remove Carbon Dioxide from the Atmosphere: Spruce Forest Tales!

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Introduction

In almost every forest we look at today we find that there is a net removal of carbon dioxide (CO_2) from the atmosphere and carbon (C) is accumulating in the soil and trees (Griffiths and Jarvis, 2005; Hyvönen *et al.*, 2007a). This is not surprising in the boreal and north temperate forests because all the C now present there has accumulated since the last glaciation. It is also not unexpected for 19th- and 20th-century plantations because they experience ongoing managerial disturbance (site preparation, thinning, harvesting and replacement). It is, however, rather more surprising for forests in the tropics because they have been there very much longer and it was thought that their C stocks would be in a state of equilibrium, with annual removals of CO_2 from the atmosphere compensated by annual returns of CO_2 to the atmosphere, as implicit in the classical Clementsian concept of 'forest climax'.

A net gain of C by forest systems implies a lack of balance between the processes taking in CO_2 from the atmosphere and the processes returning CO_2 to the atmosphere. We define the *net primary production* (NPP) as the difference between the *gross photosynthetic production* (GPP) and the losses of carbon resulting from respiration associated with growth and maintenance of live biomass, the *autotrophic respiration* (R_A), i.e. $NPP = GPP - R_A$. It follows that the *net ecosystem production* (NEP) is the difference between the *net primary production* (NPP) and the respiration associated with decomposition and mineralization of organic materials in the soil by soil animals and microorganisms, the *heterotrophic respiration* (R_H), i.e. $NEP = NPP - R_H$.

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For a forest at equilibrium, we would expect the NEP to be zero, i.e. NPP = R_H. Conversely, for NEP > 0, NPP must exceed R_H. The worldwide lack of equilibrium in forests today is the reason why they are a large global carbon sink, currently accounting for close to 40% of emissions of CO_2 derived from fossil fuels (Read *et al.*, 2001). We need to understand why this imbalance exists now so as to be able to estimate whether it is likely to continue in the future. Here we present an analysis of reasons for the current lack of equilibrium, with the aim of increasing awareness of likely future trends and managerial options.

The Issue

The key question is why is the NEP of most forests greater than zero? Why are the world's forests in general in disequilibrium, even the tropical forests in the Amazon basin? What is driving forest NEP – why is the net primary production generally larger than the heterotrophic respiration? Globally distributed, sustained rates of NEP, as at the present time, are likely to result from globally distributed, sustained inputs to forests that maintain the lack of equilibrium between GPP and R_H. What are the likely inputs or drivers for this? There are a number of candidates for different situations. We shall consider managerial and natural disturbance, nutrition, rising atmospheric CO_2 concentration ($[CO_2]$) and temperature. First, however, we describe the losses and gains of C when a new plantation forest is established, since this features the processes and fluxes.

Losses and gains of carbon in a new plantation forest: an example

In the process of afforestation and reforestation (*sensu* Kyoto) C is generally lost from the site (Fig. 9.1b) as a result of disturbance to the soil organic matter by site preparation, such as ploughing or mounding, so that CO_2 is returned to the atmosphere and NEP is negative for several years (Fig. 9.1a). In the example shown the large C content of the heather moorland soil, exposed by deep ploughing, was very vulnerable to desiccation, oxidation and mineralization (Cannell *et al.*, 1993). This period of net carbon loss may be anything between 5 and 15 years depending on the severity of disturbance and the speed of growth of the young trees. Once the canopy closes, NEP stabilizes for a number of years (Fig. 9.1a), at an annual rate of up to 8 tC ha^{-1} for fast-growing species in favourable environments (Fig. 9.2; Magnani *et al.*, 2007). Typical *mid-rotation* annual values for well-adapted species in the temperate region are 3-6 tC ha^{-1} (Griffiths and Jarvis, 2005; Hyvönen *et al.*, 2007a), but more variable and considerably lower in the boreal regions (Gower *et al.*, 2001).

The marked loss of soil-C during the first rotation is shown in Fig. 9.1b; and the compensating recovery during the second rotation in Fig. 9.1d. This recovery of the soil-C stock is dependent on leaving the below-ground and above-ground brash (roots, stumps and lop and top) on the site. The consequence of removing stumps or of baling and removing the lop and top has in the past been evaluated in terms of nutrient removal, and this may reduce subsequent stand growth.

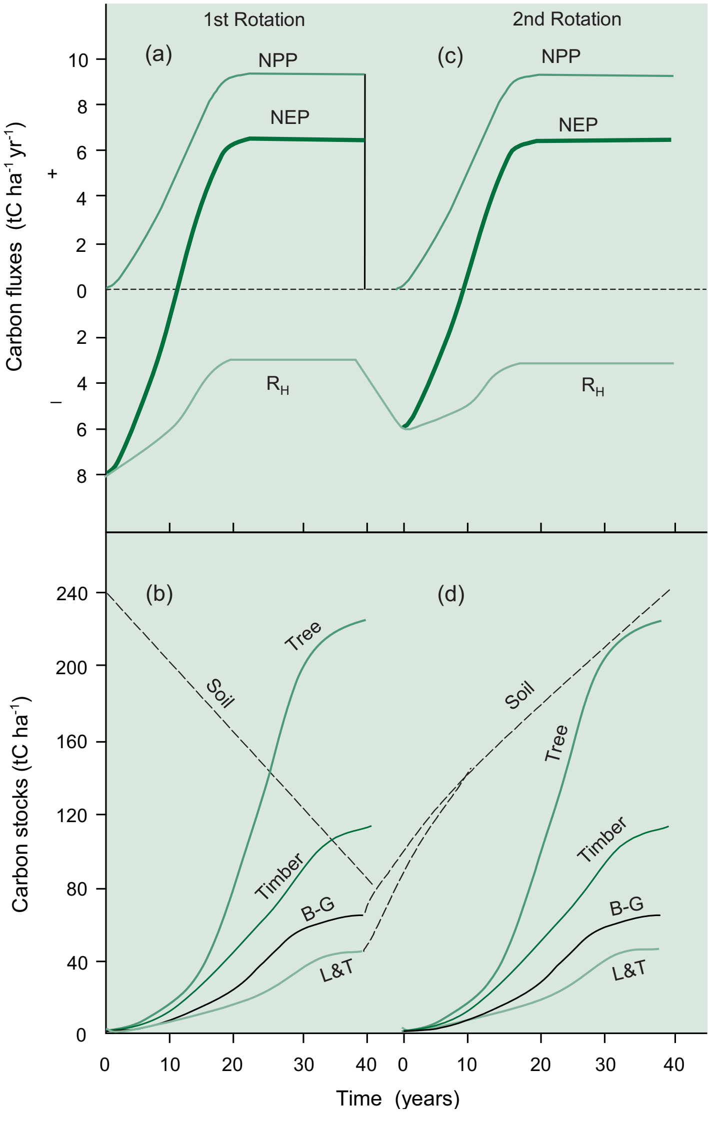

Fig. 9.1. A compiled diagram of measured and inferred CO_2 fluxes (a, c) and carbon stocks (b, d) over the first (a, b) and second rotation (c, d) of Sitka spruce forests of Yield Class 14 to 16 $m^3\ ha^{-1}\ yr^{-1}$ in northern Britain. The fluxes are based on NEP measurements made on a number of stands of different ages at Harwood Forest (Zerva and Mencuccini, 2005; Zerva *et al.*, 2005; Ball *et al.*, 2007) and since 1997 at a reference site at Griffin Forest in Northern Britain as part of the EUROFLUX and CARBOAGE programmes (Clement *et al.*, 2003). The carbon stocks (b, d) are derived on the assumption of Yield Class 16 (i.e. a mean annual *timber* increment (MAI) of 16 $m^3\ ha^{-1}\ yr^{-1}$ averaged over the rotation), scaled to mass of C and to entire trees using an average dry mass expansion factor of 1.44 ($n = 1096$) and a below-ground/above-ground dry mass ratio of 0.41 ($n = 755$) for *Picea sitchensis* (Levy *et al.*, 2004). These factors result in the following proportions of the total carbon in the trees: timber 49%, above-ground brash (lop and top, L & T) 22%, and below-ground brash (B-G, coarse roots) 29%. The total mass of tree carbon at 40 years is *c.* 230 t ha^{-1}.

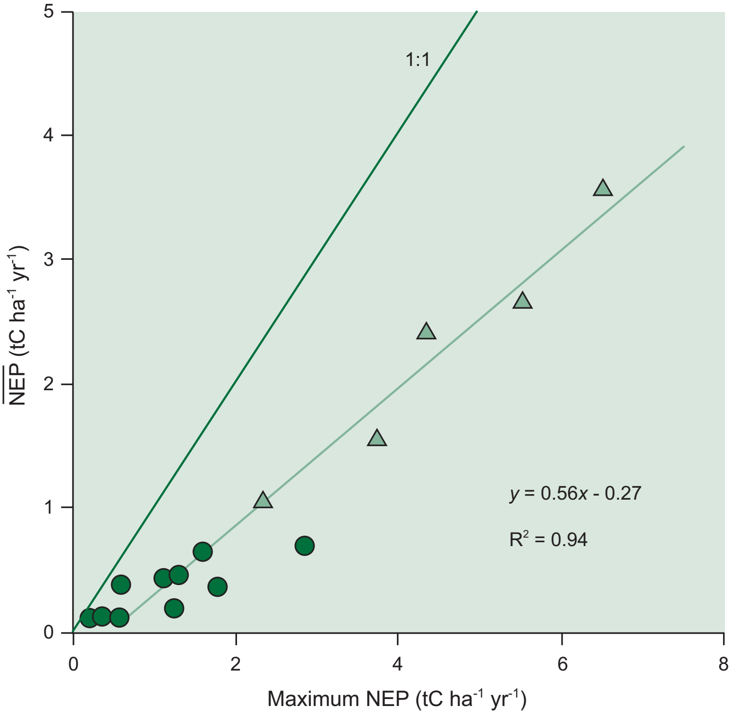

Fig. 9.2. Net ecosystem production (NEP) averaged over the entire rotation from planting through to harvest in relation to the NEP measured over one or more years in mid-rotation after canopy closure for a number of chronosequences in Europe and North America. The triangles are the five CARBOEUROPE chronosequences (after Magnani *et al.*, 2007).

However, it is also likely that such removal will reduce replenishment of the soil-C stock, but if the harvest residues are used to substitute fossil fuels it has a positive effect on the C balance (Ågren and Hyvönen, 2003). It is evident (Fig. 9.1b and d) that the soil-C stock (including roots and stumps) is comparable in magnitude to the total C stock of the trees (timber + total brash). It is important to ensure that afforestation, reforestation and other forestry activities increase the soil-C stock, rather than decrease it (cf. Johnson and Curtis, 2001; Jarvis *et al.*, 2005). We should not end up essentially 'mining' the soil-C through our management practices. Where trees grow less well in the north temperate and boreal regions, the soil-C stock considerably exceeds that in the trees by a factor of up to ×8 (Schlesinger, 1997) and consequently maintenance of the soil-C stock is even more important.

Average NEP of an even-aged compartment over an entire rotation depends on the period of time to reach the break-even year, the natural and managerial disturbances that eventuate during the rotation, age-related decline in NPP and the length of the rotation. In this instance, taking into account the initial period of soil-C loss, with consequent negative NEP over the first 12 years of the rotation (Fig. 9.1a), and integrating NEP over the entire 40-year rotation, gives the useful result that the average NEP is approximately 50% of the measured, mid-rotation NEP of *c.* 6.5 tC ha^{-1} yr^{-1} (Clement *et al*., 2003). Investigation of other chronosequences of stands suggests that this relationship is fairly representative of average NEP over a rotation, from site preparation through to clearfell (Fig. 9.2; Magnani *et al*., 2007).

A well-managed plantation forest of ideal age structure with rotation length of 40 years might be expected to comprise a number of even-aged compartments spanning that age range in more or less equal proportions, i.e. at any moment of time there would be *n* compartments of approximate age 0, 10, 40 years. The situation is a little different for largely unmanaged, naturally regenerating, so-called old-growth forests, whether in the tropics or elsewhere. Such forests tend to have all ages present in an *intimate* mixture, so that we can, in principle, take their measured rates of NEP at face value. Neither situation completely mimics reality. The age structure of a plantation forest is almost invariably biased one way or another as a result of history of ownership, subsidies and market forces; natural managed forests and old growth forests have an element of patchiness resulting from windthrow, fire, management and peripatetic exploitation.

The Drivers of NEP

Disturbance

Both managerial and natural disturbance are clearly strong drivers of NEP in particular situations. Managerial disturbance, such as site preparation, thinning and felling, leads to cyclical carbon loss and gain, as illustrated above, and managed sites with a very recent history of disturbance have generally been avoided for measurements of NEP. Although we do not know the full history of most of the sites for NEP assessment, the majority of the sites chosen have been healthy, undisturbed, productive, mid-rotation stands. Only recently has the emphasis shifted to investigation of the NEP of both deliberately managed and naturally disturbed young and old-growth sites (e.g. Bond-Lamberty *et al*., 2004; Vesala *et al*., 2005; Magnani *et al*., 2007). The example given above does not show any age-related decline in NEP, but this is likely to occur if the rotation were further extended (cf. Mäkelä and Valentine, 2001). Instead, the example shows that ongoing regular stand harvest and replacement across the entire forest ensures maintenance of the forest average NEP and increase in the soil carbon stock. Clearly what happens to the lop and top, the soil-C and the tree-C removed at harvest is crucial (cf. Ågren and Hyvönen, 2003). As pointed out, it is desirable that the mechanical disturbance of the soil by harvesting machinery should be minimized, in general by the use of brash mats, to avoid losses of soil-C. The C removed as timber from the site should, as far as possible, go into long-term storage, by replacing energy-demanding building materials such as steel, aluminium and concrete, or into the substitution of fossil fuels.

What impact does thinning have on NEP? This has been modelled, but only recently tested by experiments. In one such experiment, the stand featured in Fig. 9.1a and b was 30% thinned following conventional practice for a distance of 500 m around a flux tower when 24 years old (Clement and Moncrieff, unpublished). In the year following the thinning NEP dipped by about 20%, because GPP was reduced by more than total ecosystem respiration ($R_A + R_H$). However, the NEP returned to the average pre-thinning rate the year after, apparently because the increase in GPP as a result of thinning compensated for the increase in R_H from the addition of thinning debris to the forest floor. Thus only 2 years after the thinning, the NEP was restored to the prior 5-year average of 6.5 tC ha^{-1} yr$^{-1.}$ Similar results were reported after thinning of a Scots pine stand in Finland (Vesala *et al.*, 2005).

Harvest itself provides impetus for the maintenance of NPP. NEP is likely to go to zero immediately on clearfelling and become negative for a period, but subsequently, as regrowth takes over by natural regeneration or planting, the NEP increases again to a plateau through the next rotation. Felling in a continuous cover forestry regime may, like thinning, lead to invigoration of NEP without a lengthy period of net carbon loss; we do not as yet have the evidence. While harvest leads to long-term maintenance of NEP, in both clearfelling and continuous cover forestry the use made of the harvest products after they have left the forest is clearly highly critical to the overall forest carbon budget. Other managerial interventions may have an impact. For example, drainage some 30 years ago of a mixed Scots pine/Norway spruce stand in central Sweden is the likely cause of the current very small or negative NEP which has been evident over recent years (Lindroth *et al.*, 1998).

Natural disturbance in the recent past, such as fire and windthrow, has similar consequences, particularly where such disturbance occurs regularly. In the Canadian boreal forest, fire has an average return time of about 100 years, so that the forest is a mosaic of quite large areas in various stages of recovery, somewhat analogous to the felling coupes in a managed forest. Windthrow can similarly give rise to a patchwork of disturbance. If the trees are left lying, as in some of the more remote boreal forests, replacement of old trees by groups of young rapidly growing trees may occur resulting in greater stimulation of NPP than of R_H. In an analogous way, a patchwork of sporadic fire, windthrow and peripatetic cultivation may account for the significant NEP of mixed old-growth tropical forest.

Nutrition, [CO_2] and temperature

Many forests are deficient in readily available nitrogen (N) and phosphorus (P), particularly in the boreal and tropical regions. A number of long-term fertilization experiments, in which frequent low rates of nutrient application have been made throughout the growing season in several countries (cf. Linder, 1995; Linder *et al.*, 1996; Albaugh *et al.*, 2004), have shown large growth responses to relatively small, but regular annual additions of nutrients, particularly to N. These fertilizer experiments provide support for the view that atmospheric deposition of N may be widely supporting NEP, but also that the response depends on the availability of other essential nutrient elements, as is seen in estimations of N efficiency (C sequestered/N added) for different regions (cf. Hyvönen *et al.*, 2007b).

Through the 1950s to 1970s ‘acid rain’ caused widespread soil and water acidification, nitrogen saturation of forests, defoliation, loss of growth and death of trees. However, since the clean up in the 1980s noxious industrial emissions have been greatly reduced and the seriously damaging consequences of atmospheric pollution reduced to localized industrial areas. So today, many forests, particularly in the northern temperate and boreal regions, are benefiting from annual inputs of up to 20 kgN ha^{-1} in wet and dry deposition. The consequence of this fertilization is evident as increase in NPP and in Yield Class (e.g. Cannell *et al*., 1998; Magnani *et al*., 2007). (To put such deposition in perspective, farmers in the UK annually put 120 kgN ha^{-1} on permanent pasture.) This enhanced NPP is based on increase in leaf area and higher efficiency of photosynthesis, both of which increase removal of CO_2 from the atmosphere, thus effectively contributing to the present maintenance of the imbalance between NPP and R_H, i.e. to NEP.

Corroborative support comes from two long-term nutrient-optimization experiments with young Norway spruce plantations in the north (Flakaliden 64 °N, 19 °E) and south (Asa 57 °N, 14 °E) of Sweden (Linder, 1995; Bergh *et al*., 1999). Flakaliden is a low fertility site with low N deposition (< 4 kgN ha^{-1} yr^{-1}) and a short growing season, while Asa is a high fertility site with higher atmospheric N deposition (~15 kgN ha^{-1} yr^{-1}) and a longer growing season in the more temperate south. At both sites there was a dramatic increase in yield as an effect of nutrient optimization (Fig. 9.3) and the stands exceeded by far the yield tables for Norway spruce in the specific regions, showing that nutrition rather than temperature is the main limiting factor for growth in the boreal and temperate conifer forests (Jarvis and Linder, 2000). In the south, however, there

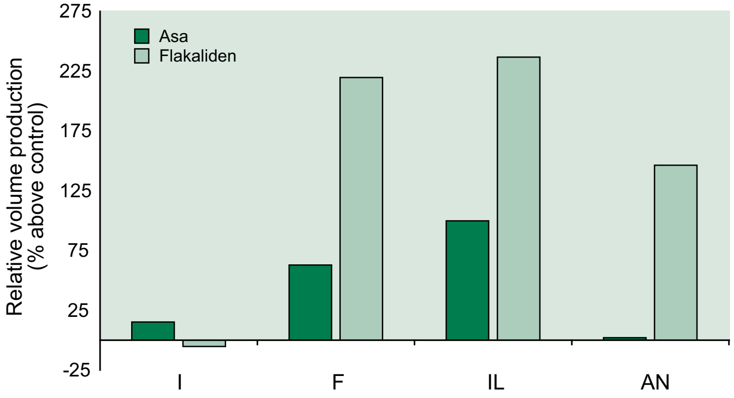

Fig. 9.3. Relative increase in cumulative stem volume production, above untreated controls, in long-term nutrient-optimization experiments with young Norway spruce plantations in the north (Flakaliden 64 °N, 19 °E) and south (Asa 57 °N, 14 °E) of Sweden for the period 1988–2000. Treatments were: irrigation (I), irrigation with a complete balanced nutrient solution in the water applied every second day during the growing season (IL), once yearly supply of a dry complete fertilizer (F), and an initial dose of wood ash (1988) followed by annual additions of N (AN) (see Linder, 1995; Bergh *et al*., 1999).

was no response to N addition unless other nutrients were added as well. The largest *relative* response to the applied fertilization treatment was at Flakaliden rather than at Asa (Fig. 9.3), but the absolute increase in yield as an effect of the optimization treatment was quite similar. The conclusion is that atmospheric N deposition is at least partly responsible for the larger ongoing NPP at Asa, but that other nutrient elements (mainly P and Mg) have become growth limiting there.

One might expect, however, that a constant input of a limiting resource such as N, that enhances GPP, would in time lead to feedbacks, such as increase in amount of leaf-fall and fine root debris that would stimulate R_H and eventually lead to a new equilibrium. In other words, to maintain a *sustained* imbalance it would seem necessary for there to be another limiting variable that is itself

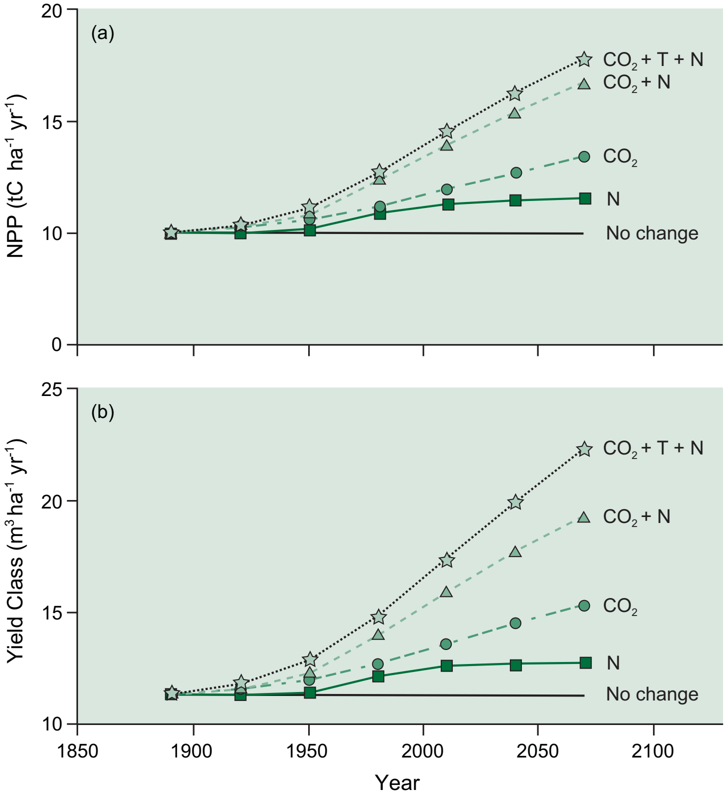

Fig. 9.4. Rotation mean NPP (t ha^{-1} yr^{-1}) of dry *biomass* (i.e. the carbon content x2) (a), and Yield Class or MAI (m^3 ha^{-1} yr^{-1}) (b), predicted by the Edinburgh Forest Model. Each point is the mean at age 30 of a 60-year rotation of Sitka spruce growing in the south of Scotland. The model was run to quasi-equilibrium prior to imposition of increases in temperature (T) of 0.1°C per decade up to 1950 and thereafter at 0.2°C per decade, giving a total of 2.5°C warming, [CO_2] from 290 ppmv in 1900 to 510 ppmv in 2050, to 690 ppmv in 2100, and in nitrogen deposition (N) from 5 kgN ha^{-1} yr^{-1} in 1940 to 20 kgN ha^{-1} yr^{-1} in 1970, and thereafter remaining constant (after Cannell *et al.*, 1998).

currently increasing. Rising [CO_2] and environmental temperature increase the possibilities for maintenance of NEP. Increase in the [CO_2] results in an immediate, direct increase of the rate of CO_2 removal from the atmosphere. It has been suggested that photosynthesis will saturate at higher CO_2 concentrations so that the effect on NPP will soon disappear. However, that hypothesis does not take into account the past and future additions of N to the forest that provide for ongoing increase in both the amount of leaf area and activity of the carboxylation system. Using two different process-based models, Cannell *et al*. (1998) showed that the increases in nitrogen deposition, [CO_2] and temperature *when taken together* could account for half the increase in Yield Class of Sitka spruce forests in the southern uplands of Scotland, over the past century, whereas when taken separately the effects of each were small. Their projections into the present century indicate that increase in NPP is likely to be maintained as a result of increasing [CO_2], combined with continued N deposition, with or without climate warming (Fig. 9.4), and this conclusion has been reached by others as well.

But what of R_H? It has also been hypothesized that the rise in temperature will lead to higher rates of oxidation and decomposition of soil organic matter, thereby increasing R_H and return of CO_2 to the atmosphere. In fact it has been proposed that at some time within the foreseeable future R_H will converge on NPP, and NEP will go to zero (e.g. Scholes, 1999), and this assumption may be implicit in the carbon cycles of some global circulation models (GCMs). That view, however, fails to take into account that N, and other nutrients, are released into the soil as a result of decomposition. This N also, simultaneously, drives increased leaf growth and carboxylation activity, contributing to increase in NPP. Even more compelling, the experimental evidence for increase in R_H in response to soil warming is equivocal (Fig. 9.5; cf. Rustad *et al*., 2001).

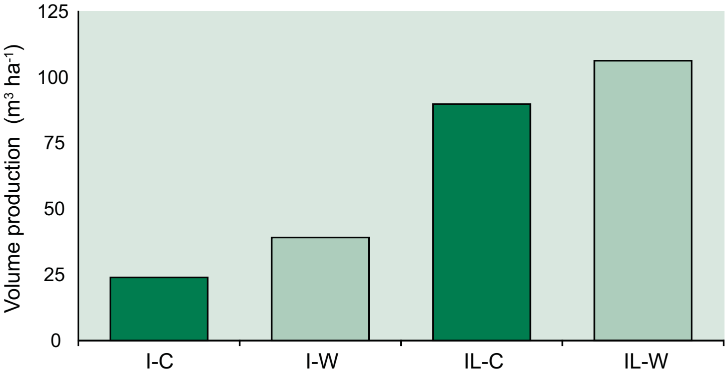

Fig. 9.5. The cumulative stem volume production of 30-year-old Norway spruce trees (in 1995) at the Flakaliden site in north of Sweden (64 °N) in response to 6 years of experimental warming (W) of the soil by 5°C at 10 cm depth throughout the growing season. The treatments were applied on plots in irrigated (I) and fertilized-irrigated (IL) stands, using non-warmed plots of the same stands as controls (C) (see Strömgren and Linder, 2001).

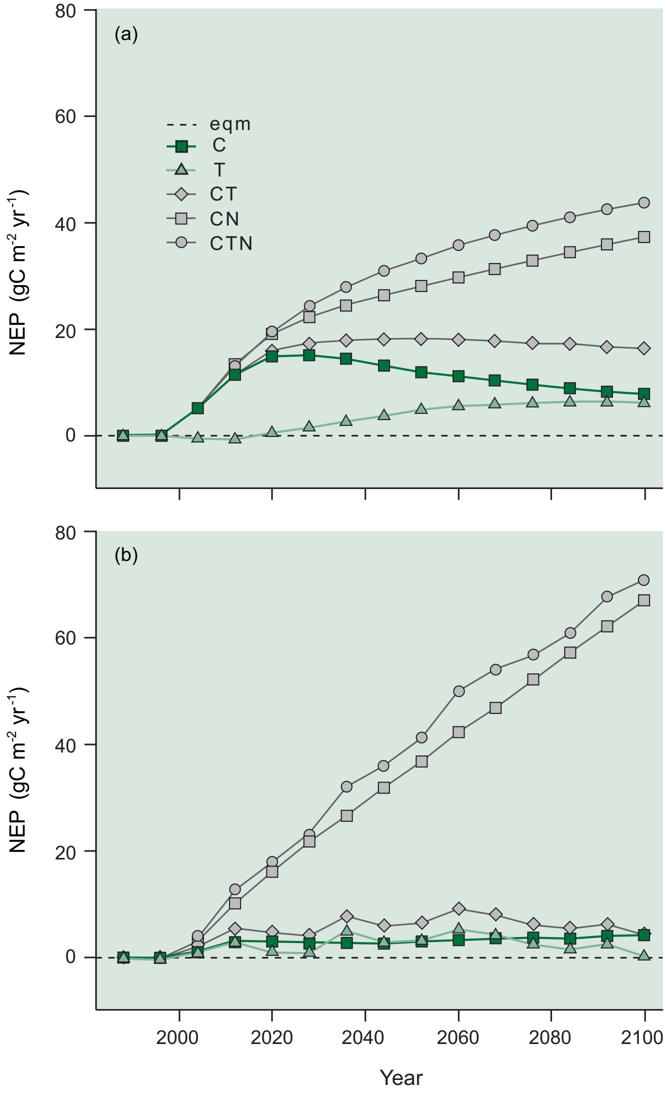

Fig. 9.6. The NEP of 30-year-old Norway spruce trees at the nutrient-limited Flakaliden site in northern Sweden (64 °N) predicted for the period 2000 to 2100 using (a) the G'Day and (b) the Daycent models (Pepper *et al.*, 2005). All curves are 8-year averages of annual NEP. Both models were run to quasi-equilibrium prior to imposition of gradual increases in [CO_2] (C), from 350 to 700 ppmv, and daily minimum and maximum air temperature (T) of 1 to 3°C, respectively. Nitrogen input to the organic N pool was increased from zero to 10 kgN ha^{-1} yr^{-1}. When applied together the increases in [CO_2] and temperature approximate the IPCC Scenario IS92a (Houghton *et al.*, 1995).

Heating the top 10 cm of soil above ambient by 5°C in large plots through the growing season at Flakaliden has shown two critical results:

1. After the initial 3 years, *the rates of release of* CO_2 *on warmed and unwarmed control plots were almost identical* (Strömgren, 2001).
2. The growth of the trees on the warmed plots, relative to the unwarmed plots, increased on both the fertilized and the unfertilized plots (Fig. 9.5).

Thus we have additional experimental evidence here to support the view that NPP will continue to exceed R_H so that NEP will continue to be maintained.

Furthermore, models which combine together current best knowledge of both carbon and nitrogen cycles come to the result that NPP may increase more than R_H in some ecosystems as climate changes so that NEP will actually increase (Fig. 9.6), or that both NPP and R_H will tend to increase together, so that NEP will be maintained (e.g. Cannell *et al.*, 1998; Medlyn *et al.*, 2000; Pepper *et al.*, 2005).

Conclusions

We have taken evidence largely from experimental investigations and modelling studies on Norway spruce growing in a low fertility, semi-continental, boreal environment and from Sitka spruce growing in a contrasting, richer, oceanic, north temperate environment. We conclude that it is very likely that the net ecosystem production (NEP) of spruce in these contrasting environments is likely to be maintained, or even to increase, as the climate changes, and hence that the extensive areas of forest of these species will continue to be significant carbon sinks.

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10

Afforestation, Reforestation and Reduced Deforestation to Sequester Carbon and Reduce Emissions

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Introduction

Afforestation and reforestation (AR) activities, as well as slowing the rate of deforestation (D), have long been recognized as holding significant potential for removing carbon from the atmosphere. Similarly, reducing the rate of deforestation holds great potential to reduce flows of greenhouse gases (GHGs) to the atmosphere. (The hot spots of change in forest area globally are shown in Plate 3). It can be seen that forest losses are mainly concentrated in South America, Central Africa and South-east Asia, whereas deforestation is significant in China and to some extent in Europe.

This chapter focuses on ARD activities in the context of the Kyoto Protocol, where Annex I countries (industrialized countries and countries with Economies in Transition) must account for emissions and removals from these activities under Article 3.3. In developing countries (non-Annex I countries), on the other hand, afforestation and reforestation can be carried out on a project-by-project basis, whereas reducing emissions from deforestation, for the first commitment period (2008–2012), is not eligible for accounting under the Kyoto Protocol.

Afforestation and Reforestation

A survey of new programmes concerning land use to sequester carbon or reduce emissions (Urstöger, 2005) has shown that few, if any, Annex I countries have implemented new policies to enhance reforestation or reduce deforestation. Schemes to support afforestation and reforestation, such as the Conservation Reserve Programme in the USA, have been going on for some time, but the

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incentives provided to countries by the Kyoto Protocol have not led to significant new efforts. One exception may be Australia, which has not ratified the Kyoto Protocol but is seeking to meet its requirements to reduce the clearing of land, particularly in Queensland. Estimated greenhouse gas emissions from land clearing in 2004 were equivalent to 53 million t of carbon dioxide (CO_2), a reduction of 75.6 million t or about 59% since 1990 (NSW DPI, 2006). Also, the New South Wales Greenhouse Gas Abatement Scheme enables companies emitting CO_2 to purchase abatement certificates to offset their emissions. Certificates can be created through renewable energy initiatives, improved energy efficiency and eligible reforestation activities (NSW DPI, 2006).

One reason for the slow uptake of afforestation, reforestation and avoidance of deforestation is that, on the one hand, establishing new forests generates GHG benefits over a period of several decades, whereas the GHG uptake is limited in the first few years due to the S-shaped growth curve of trees. Deforestation, on the other hand, is not very widespread in Annex I countries, and where it occurs it is mostly caused by infrastructure development and thus is difficult to reduce. The greatest potential for mitigation of significant size – deforestation in the tropics – has been omitted from the first phase of the Kyoto Protocol.

Afforestation and reforestation activities can be carried out at the project level under the Clean Development Mechanism (CDM). The amount of credits from these projects is limited to 1% of emissions from the purchasing (Annex I) country in 1990, times 5 (because of 5 years in the first commitment period), or approximately 500 million t of CO_2. A back-of-envelope calculation suggests that approximately only 1% of this threshold, or 5 million t of CO_2, will be achieved in practice. Therefore the impact of CDM reforestation projects in the first commitment period will be negligible.

Reasons for the minimal uptake of forestry in the CDM include:

- A delayed adoption of the rules at the 9th Conference of the Parties (COP) to the Kyoto Protocol in Milan in 2003, whereas the other sectors of the CDM were already concluded at the 7th meeting (COP7) in 2001.
- Rules and guidelines that are more complex than for other sectors.
- Lower prices for carbon credits from CDM projects due to their temporary nature, which leads to a liability for the buyer of the carbon.
- The fact that reforestation provides significant carbon benefits only in the later phases of the growth curve, which in most cases occurs beyond 2012, whereas project implementation costs occur mainly at the outset of the project.
- Credits from reforestation projects are not eligible for use in the European Emissions Trading System (EU ETS), the largest carbon market in the world.

As a result, only a single reforestation project has been validated and officially registered by the Executive Board responsible for the implementation of CDM, the Pearl River Watershed Management project in the Guangxi Province of China (UNFCCC, 2006a). The project is expected to sequester around 0.34 Mt CO_2e by 2012 and around 0.46 Mt CO_2e by 2017. It will connect fragments of forest land adjacent to nature reserves, thereby providing corridors and habitats for wildlife, and increasing biodiversity conservation in the reserves. Other environmental benefits include the reduction of soil erosion and the improvement of the regulation of hydrological flows, leading to reduced flooding and drought risks and providing incentives for people to invest in sustainable land use (BioCarbon Fund, 2007a).

The main funding entity for CDM AR projects has been the BioCarbon Fund, acting on behalf of Annex I governments and corporate buyers mainly in Japan. So far the fund has initiated more than 20 reforestation projects in Eastern Europe, Latin America, Africa and Asia, by agreeing to purchase carbon credits worth more than US$50 million.

Negotiations for a post-2012 climate agreement started at COP11 in Montreal. Regarding AR activities, the following recommendations can be made to enhance their uptake:

- Simpler methodology and project document procedures.
- Longer-term price signals, for example through commitment periods that are at least 10–15 years in duration.
- Capacity building in least developed countries.
- Broadening of the inclusion of land-use activities in the CDM, for example by including revegetation (which is the establishment of vegetation that does not constitute a forest), agricultural activities or reducing emissions from deforestation (see Chapter 11).

It is believed that AR can make the largest contribution in developing countries, due to higher growth rates, availability of land, synergies with the need for woodfuels which can be produced from the new forests ('AR projects of today provide the biomass fuels of tomorrow'), and because for many countries with low emissions from fossil fuels the land-use sector provides the only opportunity to substantially participate in the CDM.

Governments of developing countries may want to consider using the CDM to support nation-wide or regional reforestation programmes, as has been demonstrated in the case of the BiocarbonFund project in Moldova. The Moldova Soil Conservation project is reforesting 19 768 ha of degraded and eroded state-owned and communal agricultural lands throughout the country. The project is expected to sequester about 1.07 Mt CO_2e by 2012 and about 2.22 Mt CO_2e by 2017 (BioCarbon Fund, 2007b).

Reducing Emissions from Deforestation

Deforestation has a significant impact on the global carbon cycle. According to the IPCC, land-use change produced 1.6 GtC during the 1990s – approximately 20–25% of global greenhouse gas emissions for this time period (Watson *et al.*, 2000).

While deforestation is declining in developed countries, in developing countries, where the world's most carbon-rich forest ecosystems are located, deforestation rates are generally increasing (FAO, 2005). Despite the many biodiversity, climate and cultural benefits they provide, forests in these countries are losing ground to the pressures of shifting agriculture, population growth and the unsustainable exploitation of forest resources (Geist and Lambin, 2002).

Rules for the first commitment period of the Kyoto Protocol exclude from the CDM activities that reduce emissions by slowing or stopping deforestation in developing countries. At the time these rules were drafted, some groups were opposed to any inclusion of land-use-related activities in the CDM over concerns that their inclusion would reduce pressure on countries to cut emissions from fossil fuel use. Additionally there were concerns over how emissions and the reduction of emissions from deforestation could be monitored, and whether such a mechanism would merely displace deforestation outside of activity boundaries. There was also some confusion over the dual role of forests as both stores of carbon and sources of carbon emissions, which further complicated negotiations. Since the numerical emission reduction targets had already been set for Annex I countries, further concerns were voiced that new mechanisms were merely an attempt by some countries to effectively weaken the agreed targets. The controversy around these issues led to an agreement which included only afforestation and reforestation activities, leaving no provision for the protection of standing forest carbon stores in non-Annex countries (Skutsch *et al*., 2007).

In November 2005, at COP/MOP1 in Montreal, the governments of Papua New Guinea and Costa Rica, supported by several developing countries, submitted a proposal for the consideration of reducing emissions from deforestation in developing countries under the UNFCCC (UNFCCC, 2005). The proposal received wide support from both developed and developing countries. Parties agreed to a 2-year process of evaluation of the issue, beginning with negotiations of the Subsidiary Body for Scientific and Technological Advice (SBSTA), in Bonn in mid-May. At SBSTA 24 Parties agreed on the scope of an official workshop on the subject, which took place in Rome in August 2006. At the workshop several leading scientists in the fields of remote sensing and forest inventories made presentations on technical capacities related to monitoring emissions from deforestation. The SBSTA chair's report on the workshop acknowledged that 'tools, methods and data are available and the science is robust to monitor and estimate emissions from deforestation with an acceptable level of certainty', while also pointing out that other factors such as financial and human resources are key, and the effectiveness of methods could vary under different national circumstances (UNFCCC, 2006b).

Following the Rome workshop, Parties continued their evaluation during negotiations at COP/MOP2 in Nairobi in November 2006. They agreed to hold a second workshop (in Cairns, Australia in March 2007), focusing more narrowly on policy options and the specific technical issues related to them. In the Nairobi conclusions Parties also agreed to accept submissions on the topic from Parties and accredited observers to inform the second workshop, and acknowledged the potential need for a third workshop, background paper or further meetings or consultations.

Several proposals have been made by different groups for policy mechanisms to address emissions from deforestation in developing countries. The Coalition for Rainforest Nations has supported an approach that includes a market-based mechanism linked to the commitments of Annex I countries, whereby those developing countries that have the capacity could monitor and reduce emissions from deforestation and be compensated through the sale of credits on the international carbon market. Brazil has proposed a mechanism which would reward participating countries that reduce emissions through a fund supported by Annex I countries. The concept of the Brazilian proposal includes a voluntary national-level sectoral target for emissions from deforestation, relative to a 'reference emission rate'. The reference emission rate would be calculated according to a predefined reference deforestation rate and an agreed quantity of carbon per unit of land that is deforested. Those countries that reduce emissions from deforestation below their reference emission rate would then earn access to the fund. The amount collected from Annex I countries would be divided among the successful participating developing countries in the same ratio as the emissions reductions they have achieved (UNFCCC, 2006c). If a country was above its reference level, it would not have to pay a penalty, but would deduct the shortfall from future emissions, and thus reduce future access to the fund.

As the December 2007 deadline to reach a conclusion draws closer, several key issues must be addressed in order to obtain agreement and progress on a future policy mechanism for reducing emissions from deforestation in developing countries. Parties must agree on how to address the scale of such a mechanism. Several developing countries are, for the first time, seeking a mechanism that would include a national-level (sectoral) target, as opposed to project-level activities. However, a project-level approach is still preferred by some. Whether flexibility regarding the scale of the approach will be included in the policy mechanism remains to be determined.

The applicability of a mechanism to all non-Annex I forest countries is also a major challenge. Not all developing countries with tropical forests are currently experiencing high levels of deforestation, and not all deforestation trends are rising. Countries that have already begun to address deforestation with domestic policies, and those countries where deforestation rates are historically low, are actively seeking to shape a future mechanism so that they will receive support to continue reducing emissions from deforestation or to resist future pressures on their forests. This range of levels of deforestation poses a significant challenge, especially for a mechanism based on rewarding progress compared to a historical baseline of deforestation.

Another challenge is that of setting country-specific targets. If targets are too lenient, they may lead to so-called 'hot air', i.e. emission credits that can be sold without actually having reduced emissions. On the other hand, if targets are too strict, countries may easily fall out of compliance, and there may then not be a realistic chance of benefiting from this mechanism.

Countries must also come to an agreement on how such a mechanism would be funded. A mechanism which does not allow for the generation and sale of credits on the carbon market is faced with the serious challenge of generating sufficient financial support solely through a voluntary fund or tax on developed countries, and more traditional ODA-based assistance. A 'basket approach' that includes ODA funding for capacity building, as well as market access for those countries that are willing and technically and institutionally able to take on a voluntary target, may provide the most effective strategy for addressing the range of capacities of participating countries and the level of financing needed to reduce emissions from this globally important source.

Conclusions

The Land Use, Land-use Change and Forestry (LULUCF) sector is an important part of the causes of rising greenhouse gas concentrations in the atmosphere, but it can also contribute to the objective of the United Nations Framework Convention on Climate Change (UNFCCC), stabilizing concentrations of gases in the atmosphere. The relative importance of this sector is larger in developing than in developed countries, since agriculture and forestry are important parts of the economies of these countries. In fact, for many countries LULUCF is the largest source of GHG emissions, such as in Brazil where emissions from deforestation constitute 75% of total emissions.

Afforestation, reforestation and deforestation are included under the Kyoto Protocol, but will make only a marginal contribution towards meeting commitments. The largest potential emissions reduction is from deforestation in developing countries, and this source has been omitted from the first Commitment Period. Fortunately, the policy process has recognized this shortcoming and initiated a policy dialogue with the intent of reaching a conclusion by the end of 2007.

Among the key questions is whether there will be a mechanism that quantifies emission reductions and ties payment to this success indicator, and whether the mechanism will be tied, at least partly, to global carbon markets. In order to support the ultimate objective of the Convention and to ensure increased demand for a new source of emissions reductions, a market-based mechanism must be closely linked to deeper emissions reduction commitments of Annex I countries. If this linkage is not made, then emissions from deforestation may again be framed as a means to avoid domestic fossil fuel emissions reductions. It is therefore welcome that, unlike in the negotiations for the Kyoto Protocol's first commitment period, this LULUCF mechanism is negotiated *before* a conclusion is reached on quantitative targets for Annex I countries.

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11 Energy and Fuelwood

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Introduction

Woody biomass is widely utilized as feedstock for heat, electricity and cogeneration plants. In future it could also be sought by developers of biofuel processing plants, biorefineries and hydrogen production plants, but will compete with other biomass sources (OECD, 2004). The costs of biomass feedstocks vary widely. Wood processing residues are usually free on site unless there are competing uses for the material which gives them a greater value. Conversely, under some situations these residues can have an associated cost for their disposal that could be avoided if they were used for heat and power generation on site. These savings can then offset the total project costs. Residues from pruning, thinning and harvesting (termed 'arisings') are usually left on the forest floor and are costly to collect. However in systems where whole trees are hauled out on to a central landing at the roadside for processing and extraction of the logs, the arisings accumulate there and can then be cheaper to collect. Since there are many variables it is therefore difficult to determine a delivered cost range ($\$GJ^{-1}$ or $\$t^{-1}$) for woody biomass feedstock at a bioenergy conversion plant gate. Other variables include plant location, transport distance, types of machinery selected and the supply chain systems employed. Bioenergy conversion facilities also often operate with uncertain fuel supplies because the low value fuelwood currently available could become more valuable feedstock for newly developing markets. For example sawdust could be pelleted and exported rather than used as fuel on site.

The efficiency of conversion in bioenergy plants tends to be lower than for similar fossil fuel plants due to variability in feedstock quality, especially moisture content, and the smaller plant capacities that are typical. Scale is often limited by feedstock availability constraints, although the world's largest bioenergy plant in Finland generates 265 MW of electricity, 100 MW of steam and 60 MW of district heat, and brings in 60 truck loads of biomass each day from long

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distances. The market potential for woody biomass is also constrained by the challenges for plant developers to obtain long-term feedstock supply contracts and resource consents for plant construction. Hence fewer plants have been built than had been earlier envisaged. This chapter examines how these issues relate to the carbon mitigation potential of using fuelwood for bioenergy.

Supply Chain

The prime objective of a fuelwood supply chain should be to deliver the woody biomass to the power plant as cheaply as possible but in an acceptable form and quality in terms of moisture content, soil contamination, desired particle size and without including treated timber with heavy metal or salt accumulation. Poor decisions relating to the choice of harvesting, transport and processing equipment, or poor matching of the various components of the fuel supply chain, can lead to unacceptably high costs and unacceptable fuel quality. This in turn can lead to problems in the operation of the conversion plant and possible increases in emissions of local pollutants. To compete with fossil fuels, biomass must have a relatively low cost. Hence minimizing the supply chain costs is essential to achieve increased uptake of fuelwood feedstocks in bioenergy plants.

Harvesting techniques for one forest may not suit another due to variations in terrain, soil type, tree form and size. For traditional systems the stemwood is first extracted then the leftover arisings that remain in the forest or at the roadside landing are collected as a separate operation for use as biomass. Such harvesting methods could be adapted to harvesting thinnings or purpose-grown energy forests. There is, however, a growing trend towards ‘integrated harvesting’ of stemwood and arisings for co-products linked into one process at the landing.

A key interaction exists between transport costs, maximizing payloads, moisture content and particle size, as well as the energy balance and the rate of burn, fermentation or hydrolysis depending on the conversion system used (Sims, 2003). This interaction can be illustrated by a 40 m^3 capacity high-sided truck and trailer unit with a 26 t maximum payload. When used for carrying wet biomass between 50 to 70% mcwb (moisture content wet basis, Fig. 11.1a) the load is weight constrained whereas below around 50% mcwb it becomes volume constrained and the energy carried per load remains between 200 and 250 GJ. The delivered cost ($\$t^{-1}$) increases with lower moisture content due to a lighter load (Fig. 11.1b) but the more important $\$GJ^{-1}$ cost initially reduces then stabilizes when the load is below around 50% mcwb (Hall *et al.*, 2004). Larger capacity plants involve more vehicle movements and additional transport costs (Table 11.1) but economies of scale can be more significant (Dornburg and Faaij, 2001).

Detailed modelling studies of transport options have been carried out to compare a range of systems. For example, a New Zealand study showed delivered costs ranged between US$1.50 and 4.00 GJ^{-1} when selecting different supply chain equipment for harvesting, collecting and delivering the biomass to deliver the same forest arisings over the same route to an energy plant located in the Nelson region of New Zealand (Fig. 11.2). The arisings, purchased for around

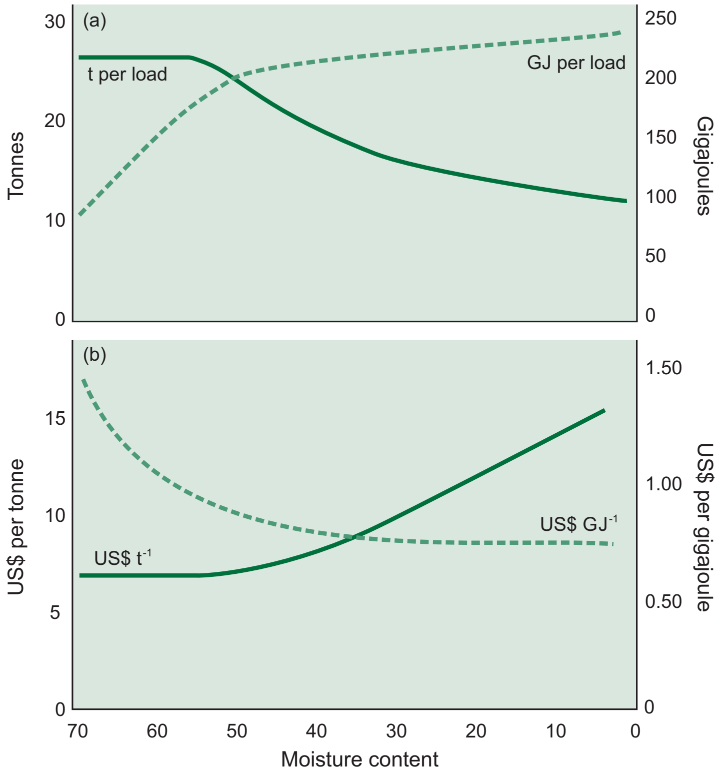

Fig. 11.1. Weight and energy per load at various moisture contents giving delivered energy costs (US\$ t^{-1} and US\$ GJ^{-1}) of woody biomass when using a 26 t maximum payload truck over a cartage distance of 35 km and based on a charge of US\$0.42 t^{-1} km^{-1}.

US\$4 per oven dried tonne (odt), were sourced from a local forest with an average transport distance to the conversion plant of 80 km (Hall *et al.*, 2004).

Another study in Australia (Stuckley *et al.*, 2003) analysed two supply systems for woody biomass produced either as a short rotation coppice crop or from forest thinnings in both wet and dry regions (Fig. 11.3). Machine capacities, work rates and cost estimates resulted from detailed modelling analyses.

The delivered costs of short rotation coppice, excluding the biomass purchase price, ranged between US\$0.90 GJ^{-1} over a 10 km transport distance in a wet region with a 2-year rotation to around US\$1.40 GJ^{-1} over 40 km in a drier region with a 4-year rotation. Thinnings could be harvested and delivered for between US\$1.00 GJ^{-1} where forest yields are good and average transport distances are below 80 km, but reach over US\$1.80 GJ^{-1} in less productive regions where the collection radius is 150 km. The shorter lead time needed to provide feedstock from harvesting short rotation crops within 2 to 4 years after establishment was a major advantage compared with waiting 8 to 17 years after planting before thinning.

Table 11.1. Typical transport requirements to meet biomass demands for various sizes and types of plant with land area requirements for plantation forests or purpose grown short rotation coppice energy crops.

Type of plant	Heat$_{(th)}$ or power$_{(e)}$ capacity range and annual hours of operation	Biomass fuel required (odt yr^{-1})[a]	Vehicle movements for biomass delivery to plant	Land area required (% of total within a given radius) to produce the biomass
Small heat	100–250 kW$_{th}$ 2000 h	40–60	3–5 per year	1–3% within 1 km radius
Large heat	250 kW$_{th}$–1 MW$_{th}$ 3000 h	100–1200	10–140 per year	5–10% within 2 km radius
Small CHP[b]	500 kW$_e$–2 MW$_e$ 4000 h	1200–5000	150–500 per year	1–3% within 5 km radius
Medium CHP	5–10 MW$_e$ 5000 h	30 000–60 000	5–10 per day	5–10% within 10 km radius
Large power plant	20–30 MW$_e$ 7000 h	90 000–150 000	25–50 per day and night	2–5% within 50 km radius

[a] odt yr^{-1}: oven-dried tonnes per year.
[b] CHP: combined heat and power.

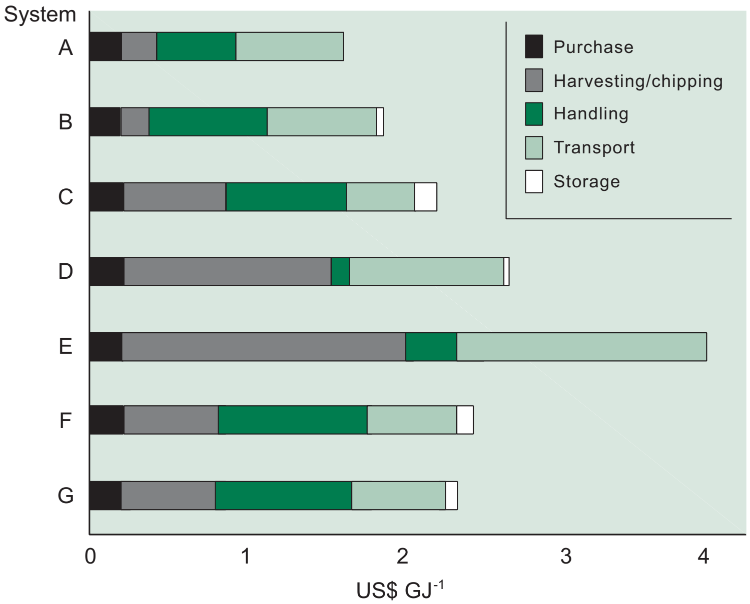

Fig. 11.2. Summary of costs (US$ GJ^{-1}) of forest arisings from a single site delivered 80 km to the bioenergy processing plant gate over an identical route but modelled using seven different collection and transport system options: A–G (Sims, 2003).

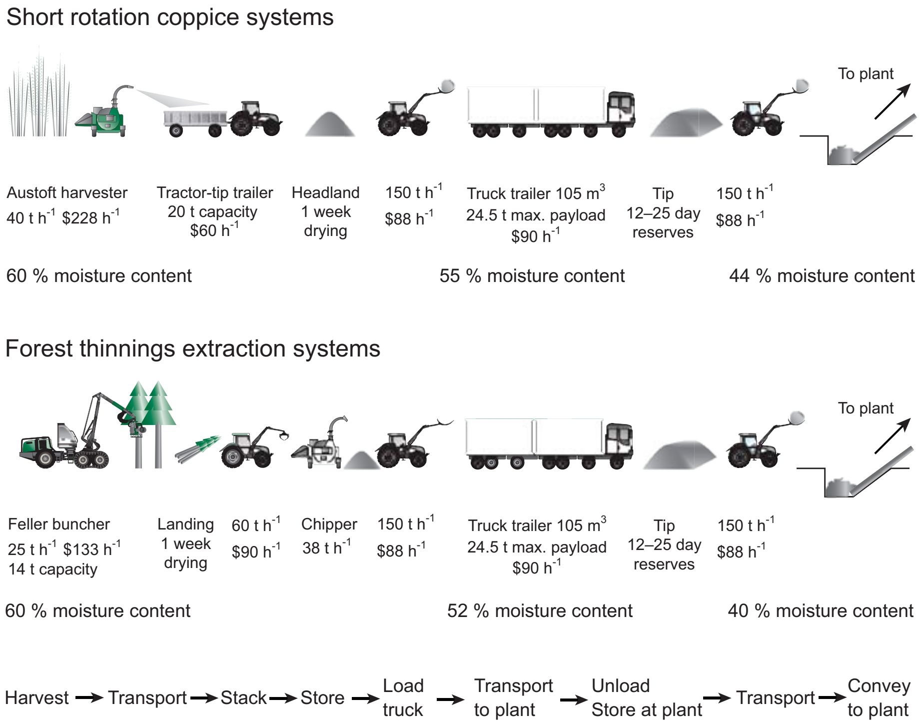

Fig. 11.3. Selected systems for harvesting short rotation coppice crops and plantation forest thinnings based on assumed machine capacities, work rates, hourly costs and moisture contents (wet basis).

Conversion Technologies

A wide range of conversion technologies are under continuous development to produce bioenergy carriers for both small- and large-scale applications. Combustion for heat and steam generation remains the state of the art. Biomass pellet and briquette heating systems for domestic and small industrial heat supply are popular due to their convenience and the potential for developing countries to export their surplus biomass since pellets are portable, flowable, have consistent quality, low moisture content, normally do not need binding agents and have a higher energy density than the original wood (www.WorldBioenergy.se: 2006).

Worldwide, more than 150 coal-fired power plants in the range 50–700 MWe now have operational experience of co-firing with up to 15% biomass by energy content, at least on a trial basis. Technical risks associated with co-firing can be reduced to an acceptable level through proper selection of biomass type and matching with the co-firing technology.

Biomass integrated gasification combined cycle (BIGCC) systems and pyrolysis to bio-oil are yet to reach commercial maturity, and await further technical breakthroughs including gas clean up and increased efficiency and reliability. Gasification has a relatively high conversion efficiency (40–50%) when used to generate electricity using a gas turbine but lower (30–35%) when using a smaller-scale, gas-fired internal combustion engine. Several pilot and demonstration projects have been evaluated with varying degrees of success. The gas produced can also be used as feedstock for a range of liquid biofuels.

Biofuels for transport

Concerns about conventional oil supply security, fluctuating prices and greenhouse gas emissions have created considerable interest in biofuels. They are available alternatives to petroleum products (as are oil sands and coal- and gas-to-liquids), whereas hydrogen may only become available in the medium to long term. Second generation bioethanol and synthetic diesel from Fischer Tropsch processing, both using ligno-cellulosic feedstocks, are near to medium-term options since at present both remain relatively high cost (Fig. 11.4). However technology development and the establishment of larger scale plants by 2030 could lower production costs to around US$0.23–0.65 per litre gasoline equivalent (lge) for bioethanol and US$0.70–0.85 per lge for synthetic diesel.

Market Potential

The role that fuelwood will play in the future global mix of consumer energy supply will depend on the ability to overcome barriers that inhibit project development and commercial investment. Project implementation has often been constrained by fuel availability, high capital costs, poor public image, regulation and resource consent processes. More active involvement by bioenergy industry associations has been undertaken in the past few years to nurture and promote the fledgling sector, overcome barriers, lobby policy makers and gain enhanced market deployment.

For a project to be ‘bankable’, the investor must have confidence that it will proceed satisfactorily without delays and will continue to operate profitably over the long term. In this regard, several broad questions need to be answered by bioenergy project developers, stakeholders, decision makers and investors.

- What types and quantities of sustainably produced biomass resources are procurable?
- What impacts will the increased use of biomass in a region have on water supplies, the environment, and social issues of employment, health, equity and development?
- What suitable supply chain and conversion technology developments will become available in the near future?
- Will bioenergy carriers be generated more efficiently than at present and become more environmentally acceptable?
- What level of investment will be needed to establish the proposed bioenergy project, not just for plant construction, operation and fuel purchase but also

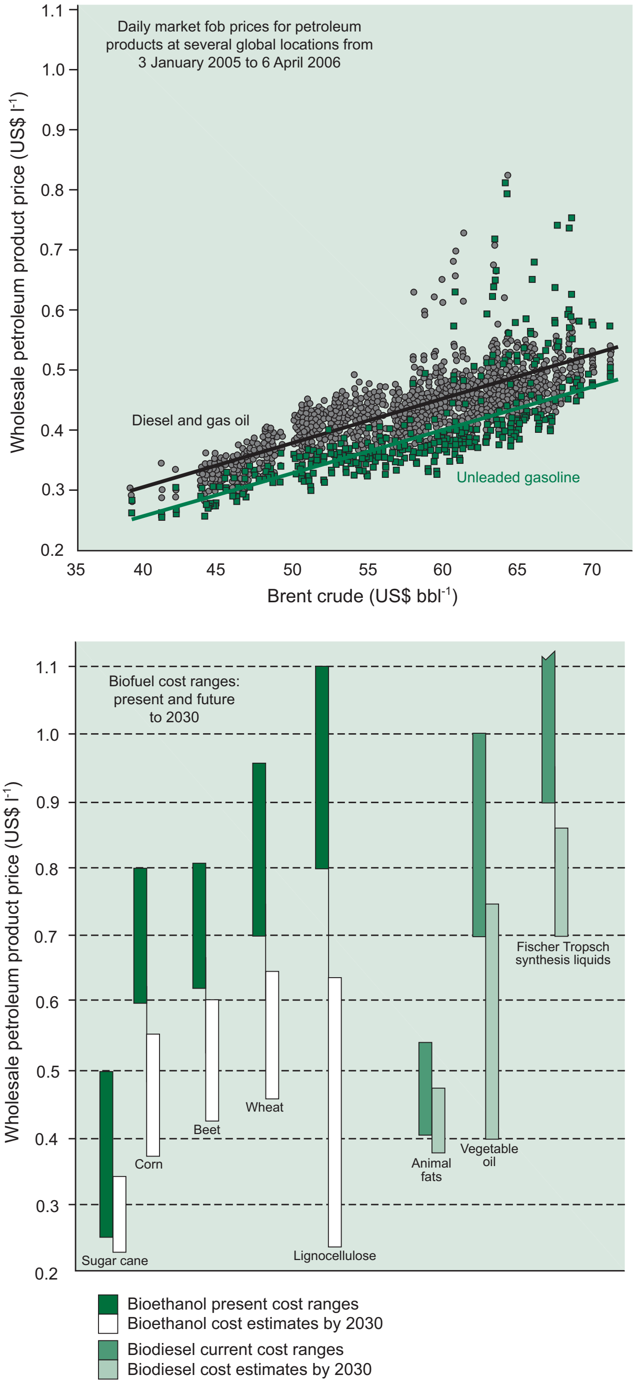

Fig. 11.4. Comparison between current and future biofuels costs versus daily gasoline and diesel ex-refinery (fob) prices at 12 worldwide locations based on a range of crude oil prices over a 16-month period; bbl : barrel.

for obtaining the necessary resource consents and negotiating the numerous related legal contracts?

- What markets for the bioenergy products exist now or will be established in the future?
- Is the level of risk from investing in such a business acceptable given its return on investment and related greenhouse gas (GHG) mitigation potential?

Bioenergy plants are likely to become most popular in the 5–100 MW range, although many heat projects will be below 5 MW_{th}. The global trend towards distributed energy may provide further opportunities for cost reductions due to technical learning and capital/labour substitution. For example, capital investment costs for a biomass-fired, high-pressure, direct gasification, combined-cycle plant up to 50 MW_e are estimated to fall from over US\$2M MW^{-1} to around US\$1.1M MW^{-1} by 2030, with operating costs, including delivered fuel supply, also declining to give generation costs around US\$0.10 to 0.12 kWh^{-1}. Commercial bioenergy options using, for example, small-scale steam turbines or Stirling engine systems can generate power for between US\$0.07 to 0.12 kWh^{-1} with the opportunity to further reduce the capital costs by mass production and experience (Sims, 2003).

Good practice guidelines

Developing a bioenergy plant can be a challenging process. Securing reliable and cost-effective supplies of biomass feedstocks, produced in a sustainable manner over the operating life of the plant, can prove to be difficult. The development of bioenergy projects could be facilitated by providing good practice guidelines for use by policy makers, local resource consenting authorities, plant developers and biomass feedstock suppliers so that proposals for a range of bioenergy projects can proceed expediently and in an appropriate manner. This will help to ensure that the biomass sector maintains its reputation for being responsible with regard to minimizing the potential environmental and social impacts that a project might bring to a community.

Bioenergy projects are usually considered to be environmentally acceptable in that they provide renewable sources of energy with low or even zero GHG emissions. However, as for any energy project, they can also have local impacts so they are not always readily acceptable to members of the local community. As well as evaluating the economic viability of a project, a developer will therefore need to consider any related social issues together with the local, national and even international environmental impacts (Fig. 11.5). This will require consultation with the local community together with local and regional resource consenting bodies such as local councils. Related social issues such as community cohesion, employment, rural development and health benefits can be of equal importance.

Bioenergy projects can range from a small, local on-farm 10 kW heating plant to a large scale 400 MW commercial cogeneration plant. Therefore not all projects will experience the same issues relating to their development process.

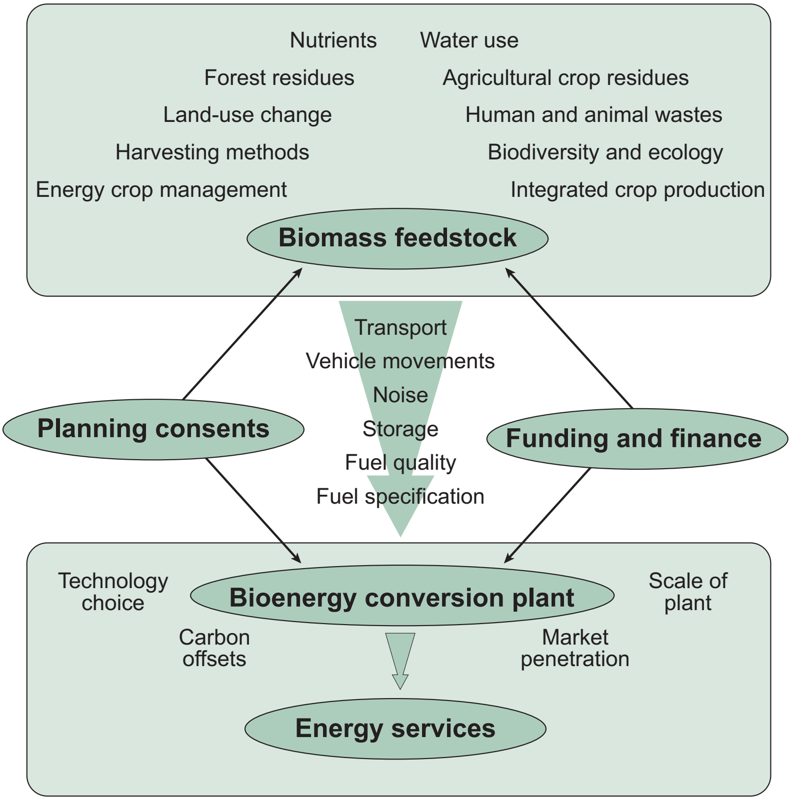

Fig. 11.5. Successful development of a bioenergy project requires consideration of a range of environmental issues by all stakeholders for both large- and small-scale plants.

There will also be major variations in the regulations imposed by local, regional and national governments. Consequently, not all issues can be equally relevant, even for similar bioenergy schemes, so a step-by-step guide for planners and developers is not realistic. However, producing a set of broad guidelines to aid bioenergy developers could be warranted to increase the rate of deployment (IEA, 2007). Many basic principles will need to be addressed by local decision makers in order to produce their own specific planning guidelines and regulations, to suit local conditions. To undertake good practice, these issues will need to be considered by project developers, even for a small scheme on a private property.

Carbon mitigation

Education and improved access to information about climate change is creating a greater awareness of the contribution of forest residues as a part solution. It has encouraged companies, communities and individuals to respond, and could result in a greater uptake of biomass projects. The choice of measure to optimize the competitiveness and GHG mitigation potential depends on the limiting factor. If the biomass resource is limiting then *CO_2 avoidance per unit biomass* should be maximized by displacing the most carbon intensive fuels. Where land use is constrained, a comparison of *CO_2 per unit land area* is of interest, and where financial support subsidies are necessary, assessing cost per *tCO_2 avoided* is paramount, taking into account co-benefits (Sims *et al.*, 2006).

Life cycle analyses are essential for comparing GHG mitigation potentials. Total energy output/input ratios of a system need to be positive but, in addition, the carbon balance of the system also needs careful scrutiny. The use of biomass is often constrained by cost. Fossil fuels remain the fuel of choice where useful energy services can be produced cheaper than from a conversion facility fuelled by biomass. In the future, however, an additional cost of carbon imposed through carbon trading would increase the cost of fossil fuels and therefore make 'carbon-lean' biomass more competitive (Sims *et al.*, 2003).

Conclusions

It is anticipated that modern biomass systems will provide a significant contribution to the global primary energy supply during the coming decades, particularly for developing countries to meet their goals for sustainable development and economic growth. However, if the economic GHG mitigation potential by 2030 of bioenergy from fuelwood is to be fully realised, more rapid project deployment than has recently been the case will be required.

Fuelwood suppliers will need to identify the optimum system to deliver the biomass to the conversion plant at a cost that is competitive with other fuels. Potential investors in bioenergy facilities will be cautious about projects with a life cycle of 15–20 years where there is uncertainty in fuel availability and no price constraints, with the project thus exposed to market risks. Therefore negotiating long-term contracts with fuel suppliers to maintain security of supply and reliable fuel quality is recommended to reduce these risks.

Over the coming decades, as the GHG mitigation benefits of biomass become better understood by investors and as carbon emissions trading expands, an increase in the total installed capacity of woody biomass-fuelled plants, including cogeneration facilities for heating and cooling together with biofuel processing, is expected. To gain public acceptance, the resource must be sustainable and renewable and the conversion plants operated with minimal impacts on the local environment.

Many potential investors in bioenergy projects do not have a good understanding of all the technical, social and environmental issues. More ready access to good practice guidelines providing information on fuel supply and quality issues, conversion plant design and technology choice, and system economics will foster greater understanding. This will enable good quality plants of appropriate design to be built at the right price to gain a good return on investment and to match the sustainably produced biomass fuels available.

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12 Carbon in Wood Products and Product Substitution

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Introduction

Wood is a complex, fibrous bio-polymer that is produced naturally as a result of the growth of shrubs and trees (Dinwoodie, 1989). It can vary in density by almost an order of magnitude. It can be supple enough to weave into baskets and rigid enough to build houses and, once pulped, it can be formed into paper. Chipped into a variety of particles and combined with glues, it can be machined into strong construction materials, soft, sound-absorbent blocks or hard, decorative mouldings. Wood is also used as a feedstock in chemical production and as a direct source of energy. Wood is almost unique in being renewable – it is possible to regrow what we use. In terms of the carbon balance, dry wood has the property of being approximately one half carbon by weight.

Humans influence the global carbon cycle by harvesting forests and producing and using wood products. Impacts on the global carbon cycle are a consequence of:

- removing carbon from the forest to make wood products;
- redistributing carbon within the forest system (e.g. leaving harvest residues on the forest floor);
- altering the dynamics of carbon exchange between the atmosphere and the living forest;
- consuming biomass and fossil fuels for the harvest, transport and processing of harvested materials;

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- using harvested products directly for energy in place of alternate sources of energy;
- using forest products in place of alternative materials in many non-energy applications.

The emphasis in this chapter is on harvested wood products that are used in ways other than as direct sources of energy. It is recognized that wood products can be a carbon reservoir, that generally it takes carbon-based fuels to process and transport wood products, and that wood products deliver services that would have to be provided in other ways in their absence. Figure 12.1 is an

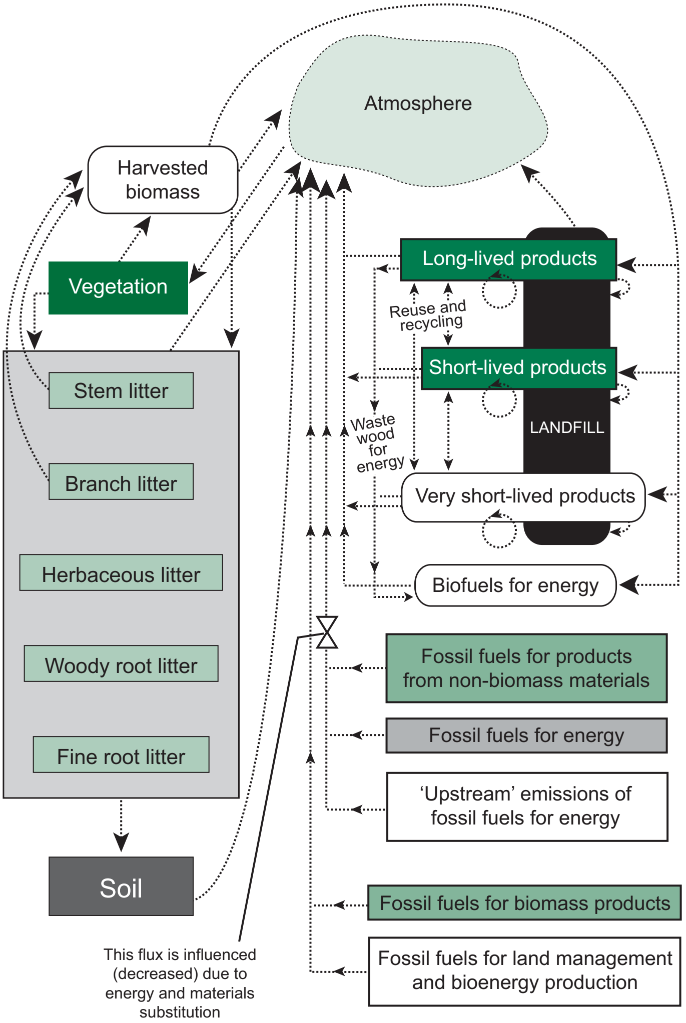


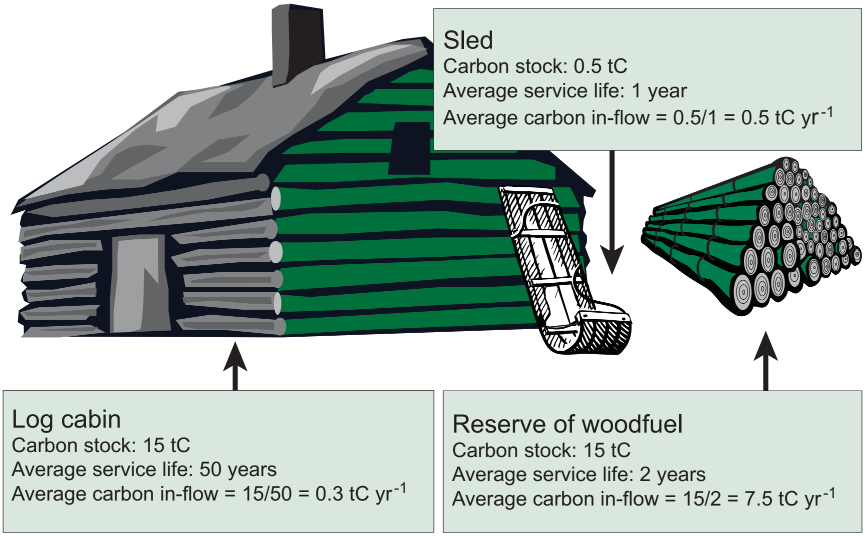
Fig. 12.1. The Graz/Oak Ridge Carbon Accounting Model (GORCAM), a spreadsheet model to account for the full carbon cycle impact of land management alternatives (after Marland and Schlamadinger, 1999).

illustration of a mathematical model that has been developed to describe the complex relationships involved in forest management and the manufacture and use of wood-based products. It describes, on the left, the stocks and flows of carbon in the forest ecosystem and, on the right, the stocks and flows of carbon in the human (economic) system. The figure emphasizes that wood products can be used, recycled and discarded and that during these steps energy is consumed and the requirements for other services and materials are altered.

With increasing concern about human perturbation of the global carbon cycle it is important to understand how human actions affect the stocks and flows of carbon and how changes in the human system might be managed to minimize impact on the climate system. It is important to appreciate the complexity and interrelationships of human impacts on the carbon cycle and this chapter focuses on establishing some qualitative relationships and general principles related to harvested wood products. Detailed discussions of methods, models, data and the current political context can be found in many papers and useful examples include Brown *et al*. (1998), Ford-Robertson (2003), UNFCCC (2003) and Pingoud *et al*. (2006).

Stocks and Flows of Carbon

Figure 12.2 is a simplified representation of the stocks and flows of carbon in wood products which illustrates the potential impacts of human activity. Wood is assumed to be harvested from a forest to maintain three wood products: a log cabin, a sled and a reserve of fuel logs. Each product is taken to contain an



Sled
Carbon stock: 0.5 tC
Average service life: 1 year
Average carbon in-flow = 0.5/1 = 0.5 tC yr^{-1}

Log cabin
Carbon stock: 15 tC
Average service life: 50 years
Average carbon in-flow = 15/50 = 0.3 tC yr^{-1}

Reserve of woodfuel
Carbon stock: 15 tC
Average service life: 2 years
Average carbon in-flow = 15/2 = 7.5 tC yr^{-1}

Fig. 12.2. A log cabin, a sled and a stock of woodfuel illustrate the relationships among carbon stocks, flows and the service lives of wood products.

annual average stock of carbon in wood: 15 t carbon (tC), 0.5 tC and 15 tC respectively (assuming fuel log stocks are replenished once a year with individual logs being used the year following harvest). Each product has an average service life (50 years, 1 year and 2 years, respectively), as determined by oxidation, attrition and, perhaps least understood, fashion. It follows by simple arithmetic that, to maintain these carbon stocks, each product requires an average annual in-flow of carbon in wood: 0.3 tC yr^{-1}, 0.5 tC yr^{-1} and 7.5 tC yr^{-1}, respectively, as shown in the figure. As long as the stock (i.e. the requirement for a particular product) is unchanged the average annual out-flow must be balanced by the average annual in-flow and, conversely, if the average annual in-flow is equal to the average annual out-flow, the stock is unchanged.

Figure 12.2 illustrates that there is a large variety of wood products and that the size of the stock and the length of the service life are independent decisions (e.g. we can have large stocks with short service lives, large stocks with long service lives, small stocks with short service lives), but that the decisions on stocks and service lives will determine the flow rates from forests to products and to disposal. Increasing the service life of a particular product may not increase the stock but may simply decrease the average annual in-flow and out-flow. Similarly, increasing the in-flow may simply decrease the service life (e.g. if the supply of a particular product exceeds demand, its price may drop to the point where people may replace the product more frequently than suggested by its full potential service life). The only way to increase the carbon stock of log cabins is to increase the number of cabins. Similarly, if the in-flow to the reserve of woodfuel is greater than the out-flow (burning), the stock of woodfuel will increase. In order to maintain the log cabin, the sled and the fuel reserve, the average annual in-flow of carbon must not exceed the productivity of the forest, otherwise the carbon stocks of the forest would be depleted over time. This implies a requirement for the forest to be sustainably managed so that carbon removed by harvest does not exceed carbon uptake through photosynthesis.

The illustration in Fig. 12.2 does not, however, tell us the full story of the relevant carbon stocks and flows. It does not tell us, for example, how much fuel was used for the chain-saw that cut the logs or the truck that transported them; and it does not tell us what sort of cabin would have been built if trees were not harvested to produce logs or how the cabin would be heated in the absence of woodfuel.

How Much Carbon?

To appreciate the importance of the stocks and flows of carbon in wood products, it is useful to have an idea of the amount of carbon involved. Skog and Nicholson (1998), for example, estimated that in the USA in 1990 the amount of carbon in wood and paper products, in use and in landfills, amounted to 2.7 gigatonnes carbon (GtC) (this was 20% of the amount of carbon in forest trees in the USA) and was increasing by 0.06 GtC per year. Similarly, Alexander (1997) reported a conservative estimate of 81 MtC for carbon stocks in wood products in use in the UK, with a further 150–250 MtC in landfills. Alexander's estimates of stocks and the associated sinks (0.44 and 4.6 MtC per year respectively) are similar in magnitude to stocks and sinks due to UK forests. Table 12.1 shows the amount of carbon in wood products produced globally in 2000, a total of 0.71 GtC – of which 0.37 GtC was in woodfuel and 0.34 GtC was in industrial roundwood.

Table 12.2 shows that the change in stocks of carbon in wood products is often as large as 1% of national greenhouse gas emissions and it amounts to 4% in the case of Austria (Pingoud *et al*., 2003). Table 12.2 also shows that wood products can affect national greenhouse gas emissions inventories by as much as 30%, if we accept alternative accounting strategies that have been proposed, as described later in this chapter. Data such as those summarized in Table 12.2 demonstrate clearly that carbon is accumulating in wood products in a number of countries. The IPCC methodology for estimating national greenhouse gas emissions, published in 1997, described a default methodology for wood products that assumed stocks were not increasing, i.e. that the rate of emissions from wood products was equal to the rate of production of wood products (Houghton *et al.,* 1997). More recent approaches (e.g. Pingoud *et al*., 2003, 2006) acknowledge that total national CO_2 emissions are often overestimated if we do not recognize the accumulation of carbon in wood products.

Methods for estimating emissions from wood products generally use data on the rate of production along with estimates of product service life and the assumption that decay is a first order batch process. In other words, the carbon in a particular type of wood product is lumped into a single pool and assumed to diminish over time according to an exponential curve. Marland and Marland (2003) describe the mathematical implications of this approach and propose that in many cases decay could be better represented as a process in which the rate of decay is distributed over time (i.e. time since production) according to a non-monotonous pattern. The problem with the first-order batch approach is that,

Table 12.1. Global production of harvested wood products in 2000. Based on data from the United Nations Food and Agriculture Organization (FAO) and assuming that coniferous wood is 0.4 t m^{-3} (dry weight), non-coniferous wood is 0.5 t m^{-3} (dry weight) and that the carbon fraction of dry biomass is 0.5 (from Pingoud *et al*., 2003.)

Products	Global production (billion m^3 yr^{-1})	Global production (Gt C yr^{-1})
Primary products		
• Roundwood	3.1	0.71
• Woodfuel	1.5	0.37
• Industrial roundwood	1.6	0.34
• Pulpwood	0.48	0.11
• Sawlogs and veneer logs	0.95	0.20
• Other	0.15	0.03
Semi-finished products		
• Sawnwood	0.42	0.09
• Wood-based panels and fibreboard	0.22	
• Paper and paperboard		0.15

Table 12.2. Total greenhouse gas emissions and the contributions due to land use, land-use change and forestry (LULUCF) and harvested wood products (HWP), by country. Values are in MtC equivalent emissions or as the percentage of total emissions in the base year (1990) without emissions or sinks due to LULUCF or HWP. Base year for emissions reported as due to LULUCF is also 1990; for HWP emissions the base year is 2000 (adapted from Pingoud *et al*., 2003).

	National greenhouse gas emissions (MtC equivalent yr^{-1})			Percentage contribution due to HWP		
Country	Total (without LULUCF or HWP)	LULUCF	HWP (stock change approach[a])	Stock change approach[a]	Atmospheric flow approach[a]	Production approach[a]
Australia	116.0	21.3	–0.6	–0.5	–0.1	–0.5
Austria	21.1	–2.5	–0.8	–4.0	–4.3	–2.4
Belgium	38.9	–1.6	–0.4	–1.0	0.9	–0.5
Canada	165.6	–16.8	–2.5	–1.5	–15.1	–5.6
Denmark	18.9	–0.2	–0.5	–2.7	3.3	–0.2
Finland	21.0	–6.5	–0.6	–3.1	–30.6	–5.8
France	152.5	–15.3	–1.8	–1.2	–0.5	–1.4
Germany	333.5	–9.2	–3.0	–0.9	–0.6	–1.0
Greece	28.6	0.4	–0.2	–0.6	1.5	0.0
Ireland	14.6	–0.0	–0.0	–1.6	–0.4	–1.7
Italy	142.0	–6.4	–1.8	–1.3	2.6	–0.3
Japan	340.0	–22.9	–0.3	–0.1	2.4	0.4
Netherlands	57.4	–0.4	–0.3	–0.5	2.3	–0.2
New Zealand	30.0	–6.0	–0.3	–1.6	–12.8	–5.5
Norway	14.2	–2.7	–0.2	–1.4	–2.7	–0.4
Portugal	17.7	–1.0	–0.3	–1.8	–4.1	–1.0
Spain	78.1	–8.0	–1.5	–1.9	2.7	–0.5
Sweden	19.2	–5.5	–0.3	–1.5	–26.1	–4.0
UK	202.5	2.4	–0.9	–0.5	2.0	–0.4
USA	1672.0	–299.4	–19.8	–1.2	–0.7	–0.8

[a] The different accounting approaches are explained in the text.

implicitly, an assumption is made that a product decays in simple proportion to the size of the stock at any time. The result is that the highest decay rates occur in the first years after production, with the rate of decay decreasing progressively from that point. Additionally, all products of the same type are assumed to decay according to the same time course regardless of when they were produced (i.e. the time when they joined the batch). This is clearly not the case for long-lived products like our log cabin. In a distributed decay model, products are not treated as a single batch, but as a series of distinct products (Fig. 12.3). If a gamma or Weibull function is used to describe the pattern of decay for each individual product type, it is possible to represent different patterns by making simple changes to the parameters of the function. Adopting this approach, as has been explored in the CARBINE forest carbon accounting model (Thompson and Matthews, 1989), enables a more flexible and realistic description of the decay

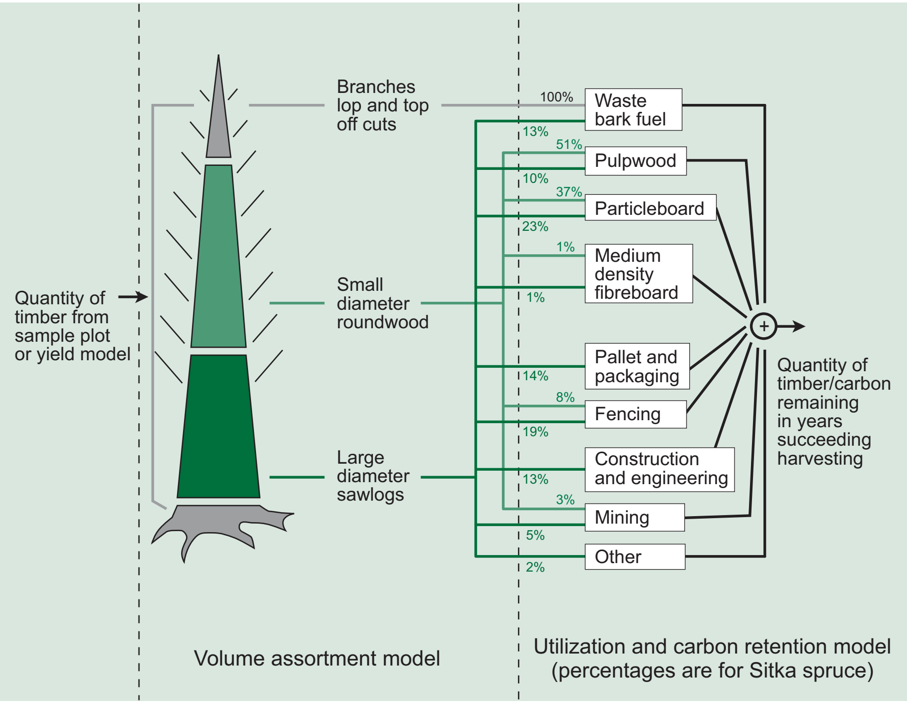


Fig. 12.3. Example of the detailed representation of carbon flows through a series of distinct harvested wood products as implemented in the Forest Research CARBINE carbon accounting model (Thompson and Matthews, 1989).

process, such as that illustrated in Fig. 12.4. The differences are frequently small, but could be important to some parties, particularly if carbon retention needs to be reported under some form of cooperative agreement or if it is valued in financial markets with discounting of future emissions. Either type of function (first order decay or a distributed decay function) can be used to recognize that wood can be recycled, sequestered in a landfill or used as a fuel after the service life of the primary product.

Life cycle analyses of wood products suggest that the emissions of greenhouse gases associated with the manufacture and use of wood products are often less than for alternative materials, such as steel and concrete, for which they potentially substitute. In fact, Buchanan and Levine (1999) report that the low fossil-fuel requirement for manufacturing wood products, compared to other materials, is often more significant to the global carbon cycle, in the long term, than is the carbon retained in the wood products. The fossil-fuel requirement of wood products is related to the efficiency of production processes and the rate at which products are manufactured, while the carbon physically retained in harvested wood is associated with changes in the stocks of wood products. In essence, the stock of wood products may saturate but opportunities to adopt low-carbon manufacturing processes (even when maintaining a constant stock of products)

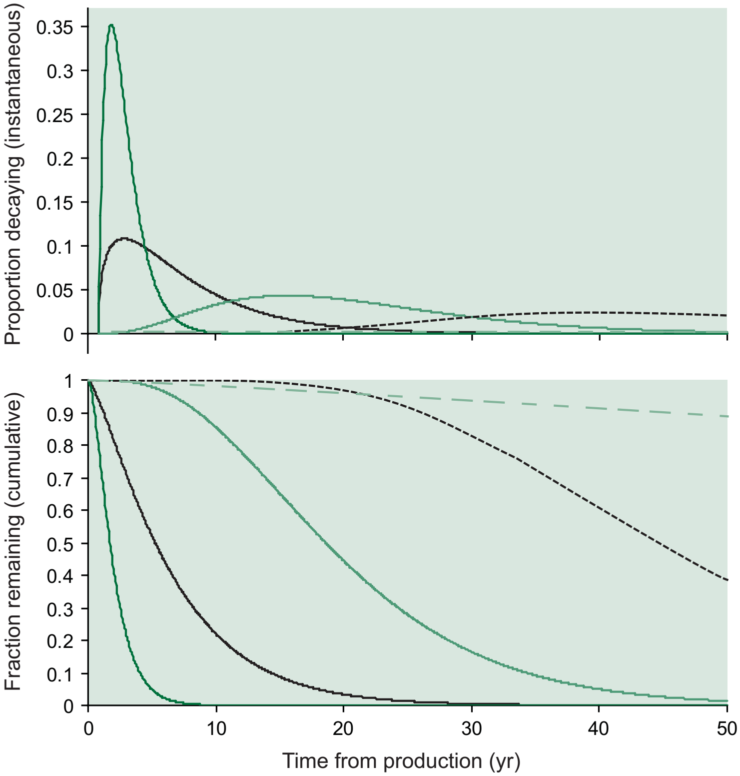


Fig. 12.4. Examples of gamma functions used to describe the rate of loss of carbon from wood products and corresponding remaining fractions of carbon in wood products since the time of their manufacture. The timing of the peak decay rate, the spread of the distribution and other characteristics of the curves are adjusted through choice of an appropriate mathematical function and by selection of values for the parameters of the function. Based on parameter values for British oak timber and four examples of specific products as represented in the CARBINE model (Thompson and Matthews, 1989).

need not saturate. Figure 12.5 illustrates the relative magnitudes of greenhouse gas emissions over the life cycle of a few construction products based on different materials. At a larger scale, Gustavsson *et al*. (2006) compared two functionally equivalent buildings and showed that wood-framed construction required less energy and emitted less CO_2 than concrete-framed construction. The analysis of Gustavsson *et al*. makes clear that use of recovered biofuels during logging, construction and demolition contributes significantly to the potential advantages of the wood-framed construction. At the national scale, a theoretical analysis by Matthews (1996) estimated that the utilization of timber from British forests was resulting in national carbon emissions that were about 6 MtC per year lower than would be the case if the same requirements were met using non-timber materials. A more recent study of the potential for enhancing the contribution of forest management and home-grown wood utilization in the UK (Tipper *et al*., 2006)

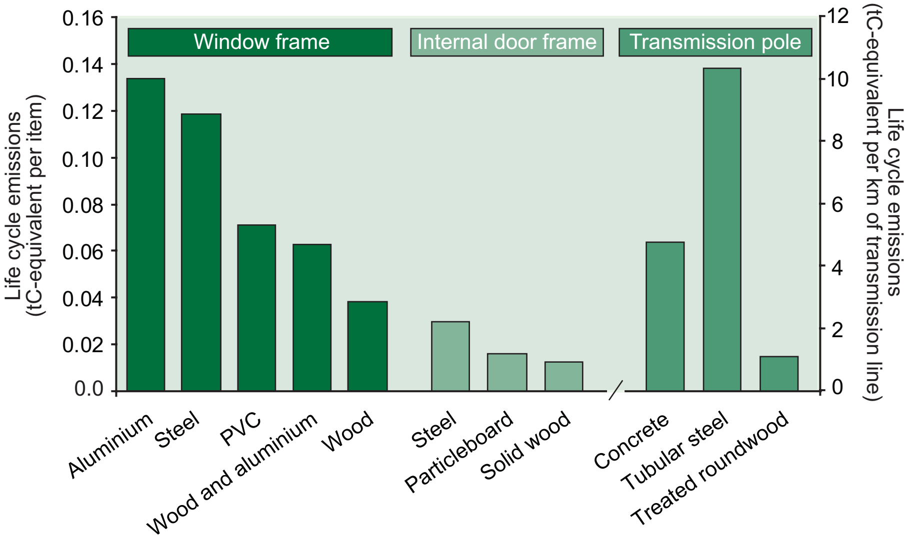


Fig. 12.5. Total life cycle emissions of greenhouse gases for three construction components where wood can substitute for alternate materials. The estimates for window frames include allowance for heat loss during the service life (based on results presented in Richter, 1998).

suggested at least 8 MtC per year of avoided carbon emissions. These estimates represent approximately 5% of current GB or UK national emissions and do not account for the contribution from a considerably greater consumption of imported timber and wood products.

Whose Carbon?

The proposal for keeping inventories of carbon retained in wood products has resulted in discussions about how the reporting and accounting should be conducted. When a forest is harvested and wood products are manufactured, which party will report the carbon stocks or flows related to wood products? If the carbon in wood products increases, will some party report the increase as part of a greenhouse gas emissions account? Will the party that grew and harvested the trees show that some of the carbon was not discharged as CO_2 when the trees were cut, or will the party that accumulated wood products show an increase in carbon stocks? In 1998, a meeting in Senegal (see Brown *et al*., 1998; Lim *et al*., 1999) outlined three possibilities for carbon reporting methods beyond the simple 'IPCC default' approach mentioned above. The 'atmospheric flow approach' would report actual carbon flows to and from the atmosphere at the time and place that they physically occurred. The 'stock change approach' would report actual stocks of carbon as wood is harvested, utilized and disposed of. The 'production approach' would also report changes in wood-based carbon stocks, with the difference that all stocks would remain attributed to the point of origin (i.e. to the party owning the forest that produced the harvested wood), regardless of where the wood products happened to reside. A more recent fourth approach, the 'simple decay approach' reports actual carbon flows to and from the atmosphere like the atmospheric flow approach but, similar to the production approach, the emissions remain attributed to the party owning the forest that produced the harvested wood.

Table 12.2 makes clear that the choice among these accounting possibilities makes a considerable difference to parties that are major importers or exporters of wood products. However, these differences are a matter of accounting system boundaries and the distinctions between 'your carbon' and 'my carbon' have no effect on atmospheric emissions.

Carbon accounting systems are sometimes used for simple reporting of inventories of carbon but also form the basis of tax or cap-and-trade systems for limiting carbon emissions. (To illustrate, a group of organizations or individuals may set a target limit – or cap – for their carbon emissions. Groups that achieve their target with room to spare may then trade the difference with other groups to help them meet their targets.) Tonn and Marland (2007) argue that accounting in support of tax or cap-and-trade systems is not just about reporting an inventory but is designed to motivate and/or reward actions towards an environmental objective. Thus, they suggest a system for sharing credits when several parties are involved in the sequestration of carbon (or reduction of emissions) through harvesting and utilization of wood. Their proposed system (see Table 12.3) is complex and leaves some details yet unspecified, but it might provide a solution to a decade-long inability to achieve international consensus among the four accounting approaches described earlier.

The UNFCCC (2003) suggests that the approach accepted for estimating, reporting and accounting for carbon in wood products could potentially affect forest management and patterns of wood utilization, with different implications for developed and developing countries and for net importers and net exporters.

Table 12.3. Sharing credits for carbon sequestration: an example of how credit for 5000 MtC might be shared for a project involving four parties (P_1–P_4) and four project components (C_1–C_4). The sum of party contributions must be 1 for each project component and the sum of the component weights must be 1 over the four components. To find the attribution fraction for each party, multiply the score for each component by the component weight and sum over the four components. To find the attribution total, multiply the attribution fraction by the total project credits (Tonn and Marland, 2006).

	P_1 Wood exporter	P_2 Project broker	P_3 Wood importer	P_4 Wood products end user	Project component weights
C_1 Wood	1.0	0.0	0.0	0.0	0.4
C_2 Brokering	0.1	0.7	0.1	0.1	0.1
C_3 Production	0.0	0.0	1.0	0.0	0.3
C_4 End use	0.1	0.0	0.3	0.6	0.2
Attribution fraction	0.43	0.07	0.37	0.13	
Attribution total (MtC)	2150	350	1850	650	

Hashimoto *et al*. (2002) agree that the potential impacts of different accounting approaches on net carbon emissions at the national level are significant and that a choice among approaches must consider the policy implications. The distinction between ‘your carbon’ and ‘my carbon’ has implications for the trade in wood products and it also has potential for perverse incentives.

Critically, while a debate continues about how to account for carbon emissions from wood products, it has been suggested in this discussion that product substitution may have more impact on the global carbon cycle than does the carbon physically retained in wood products. Yet, the ‘my carbon’/‘your carbon’ discussion has focused on the physical carbon stocks. Whereas substitution of wood products for other materials may result in a reduction of net life cycle greenhouse gas emissions, forest owners and forestry countries may not be the ones to report these reductions. Potentially, this is an example of what economists refer to as leakage. Manufacture of wood products or woodfuels by one party may result in reduced greenhouse gas emissions by a cement company, a steel mill or an electricity generating plant elsewhere.

Management of Harvested Carbon

Forest management aims to deliver a complex range of environmental, economic and social services. Thus, in general, the management of carbon stocks or supply of energy-efficient fuel and materials will be two out of many objectives addressed by national/international forestry-related policies and by local forest management plans. The constraints applied by multi-objective management of this kind suggest that there will be few opportunities to optimize forest management and wood utilization strategies based on a purely technical consideration of greenhouse gas balances. Nevertheless, there are some fundamental principles that can be referred to as part of any evaluation or ranking of options.

Theoretical analyses based on carbon accounting models such as GORCAM (Marland and Schlamadinger, 1999) suggest that there are critical thresholds in the carbon balances achieved by management of forests for protection or maximum wood production, or for some balance between these extremes (Plate 4). Model simulations indicate that initial standing carbon in forests (before implementing a particular management option), potential growth rates of forests, the relative energy requirements of wood and non-wood products and the time-frame over which a management regime operates all play a role in determining these thresholds. For example, when forests contain high levels of initial standing biomass but have low potential productivity, it can take a very long time before emissions reductions achieved through use of harvested wood compensate for the initial loss of forest carbon due to harvesting. In contrast, if opportunities for harvesting are being missed as a consequence of under-utilization of productive woodlands, then there is potential for rapid displacement of fossil fuels by bringing these into production.

The sensitivity of greenhouse gas balances to local ecological and economic factors implies that there is no ‘one size fits all’ policy or management regime that can be adopted; options need to be evaluated in particular regional or, perhaps,

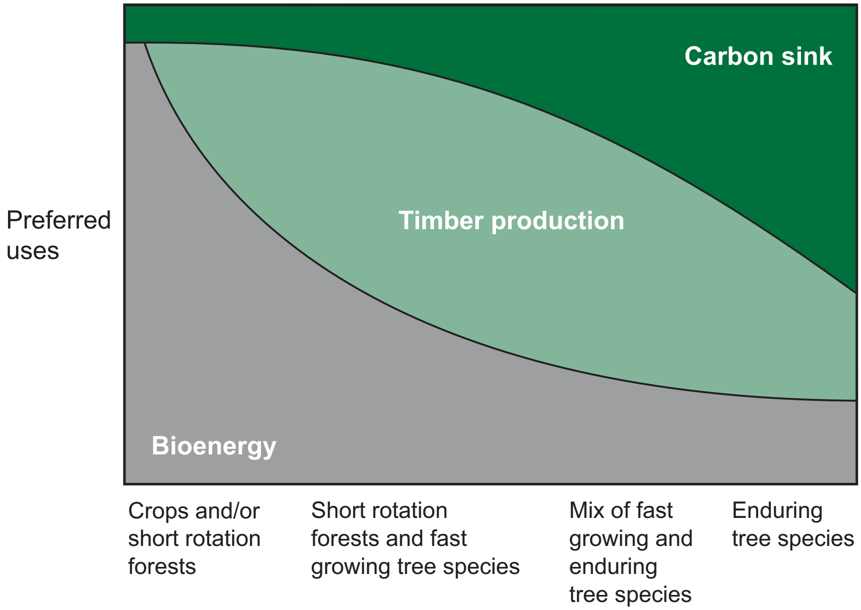


Fig. 12.6. Developing guidelines for matching forest management and wood utilization regimes with appropriate priorities for carbon management (after Matthews and Robertson, 2005).

local contexts to establish which deliver positive outcomes in terms of greenhouse gas balance. In many situations, a rigorous and detailed analysis of options may not be feasible. However, the principles behind these analyses could form the basis of simple and practical guidelines for screening forest management and wood utilization plans. An example of simplified guidelines in graphical form was reported in Matthews and Robertson (2005), emphasizing the matching of broad classes of forestry systems to appropriate priorities for carbon management (Fig. 12.6). Broadmeadow and Matthews (2003) outlined a similar approach to evaluating forestry options from a carbon perspective in the UK, focusing on three broad options referred to as ‘carbon reserve management’, ‘carbon substitution management’ and ‘selective intervention carbon management’. The potential exists to evaluate such options for different situations against critical greenhouse gas balance thresholds such as those identified by Marland and Schlamadinger (1999).

Conclusions

Production and utilization of harvested wood products can yield a net decrease in emissions of greenhouse gases to the atmosphere, but it is important to consider the specifics of how the wood is used and to look at the entire system. Emissions reductions through use of biomass fuels or product substitution may be equally, or potentially, more important than the carbon actually retained in wood products. Furthermore, recent analyses suggest that there are critical thresholds that are important in determining the carbon balance between forest protection and forest harvest.

Modern forests serve a multitude of objectives and one of these can be contributing to the mitigation of global climate change. Wood products can provide benefits in terms of low greenhouse gas emissions when the wood comes from productive and sustainably managed forests and the wood is used efficiently to increase retained carbon or to displace more energy-intensive products. It is possible to define key principles which can form the basis of easily understood guidelines for aligning forest management to the achievement of climate-conscious objectives.

It is important that accounting and reporting is simple, transparent and inexpensive because the carbon cycle benefits of wood products will often be small. Nevertheless, the greenhouse gas benefits attributable to wood products are real and will be quantitatively important to some parties. The accounting and reporting systems adopted could affect the use and trade of wood products and it should be remembered that the ultimate aim of accounting and reporting is to promote climate-friendly outcomes.

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13

Towards a High Resolution Forest Carbon Balance for Europe Based on Inventory Data

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Introduction

During the 1990s, the estimated amount of carbon (C) stored in terrestrial ecosystems increased by about 0.7 GtC yr^{-1}, calculated as the residual from fossil fuel emissions, minus the oceanic sink and the atmospheric increase of carbon dioxide (CO_2). This 0.7 GtC yr^{-1} is the net difference between an emission of about 1.6 GtC yr^{-1} from land-use changes, primarily in the tropics, and a total uptake of about 2.3 GtC yr^{-1} (Bolin *et al*., 2000). The cause and spatial distribution of this latter 2.3 GtC of terrestrial carbon uptake is the subject of ongoing debate (Houghton, 2003; Achard *et al*., 2004).

European forests are at present young, in a vegetation rebound phase and are intensively tended. Therefore they have a large potential for carbon sequestration and might play a relatively large role in the global carbon cycle. This notion has initiated intense research concerning the role of European forests in the global carbon cycle. All studies so far conclude that they act as carbon sinks, but estimates vary from 0.068 GtC yr^{-1} to 1.1 GtC yr^{-1} (Nabuurs *et al*., 2003). Some of these differences can be explained by differences in the components of the carbon cycle or vegetation types included, but most of the differences seem to be caused by the methodology used.

Aim

The largest discrepancy in results is usually found between inversion modelling (combined with biogeochemical modelling), on the one hand, and ground-based (forest inventory) modelling exercises, on the other. Comparability is

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usually difficult because of the use of a defined grid in the first methodology, and the use of regional databases in the second. This allows only for comparison of European totals. In order to improve this, we are aiming for a high resolution, inventory-based carbon balance assessment for European forests for the period 2000–2030.

Methods and Current Work

National forest inventories can be used to provide complementary, ground-based estimates of large-scale C balance that can help identify the location of C sources and sinks. Forest inventories are specifically designed to supply statistically sound measurements of timber stocks and growth across large, heterogeneous regions. These are the basis for an inventory-based C balance. To arrive at a full ecosystem balance, the stemwood volumes are complemented with (semi-dynamic) conversion factors to take into account branches, foliage and roots. Turnover of these tree components and logging slash leads to additions to the soil. Usually the soil dynamics are simulated with a (simple) soil model (Masera *et al*., 2003).

Through an intense net of sampling plots, almost every European country keeps regular track (usually with intervals of 5 years) of the state of their forests and harvest. Within the EU27 some 450 000 plots are in use; the central European countries are also in a phase of converting their inventory to a sample plot-based design. Each plot usually consists of some 25 trees on which a set of variables is measured. Measurements extend back decades in some countries.

Through enquiries to national forest inventory institutes we have received the plot level aggregated data as tree species, height, diameter, standing volume, increment, mortality and harvest for 229 000 locations. These are from 14 countries (see Fig. 13.1). The approach is to assess the current and future carbon balance for each plot separately, and to aggregate the results to 10 × 10 km grids (Fig. 13.2); this is in order to allow for validation of models in the biogeochemical cycle.

Several tasks need to be done. First, plot data have not been received or are not available for all countries (Fig. 13.1). We are still pursuing the data for Ireland, Poland, Spain and Denmark; these countries may still deliver. The next step is to overlay the tree species data (for 25 species and species groups) for those countries for which data are available on to GIS maps for site and agroclimatic factors such as soil type, temperature and elevation. From regression functions indicating relationships between tree species and these factors, the tree species distribution in countries with missing data will be estimated. For countries with missing data, we still have the coarser grid of 6000 ICP plots, regionalized tree species areas from the EFISCEN database (Nabuurs *et al*., 2006; Schelhaas *et al*., 2006) and scattered information for example in the form of hard copy tree species maps. All this circumstantial material helps to assess the full European (EU27) high resolution tree species map at a resolution of 1 × 1 km. Regionalized data are then also used to assign volume and increment to the plots, in such a way that the regional totals match with the regional data.

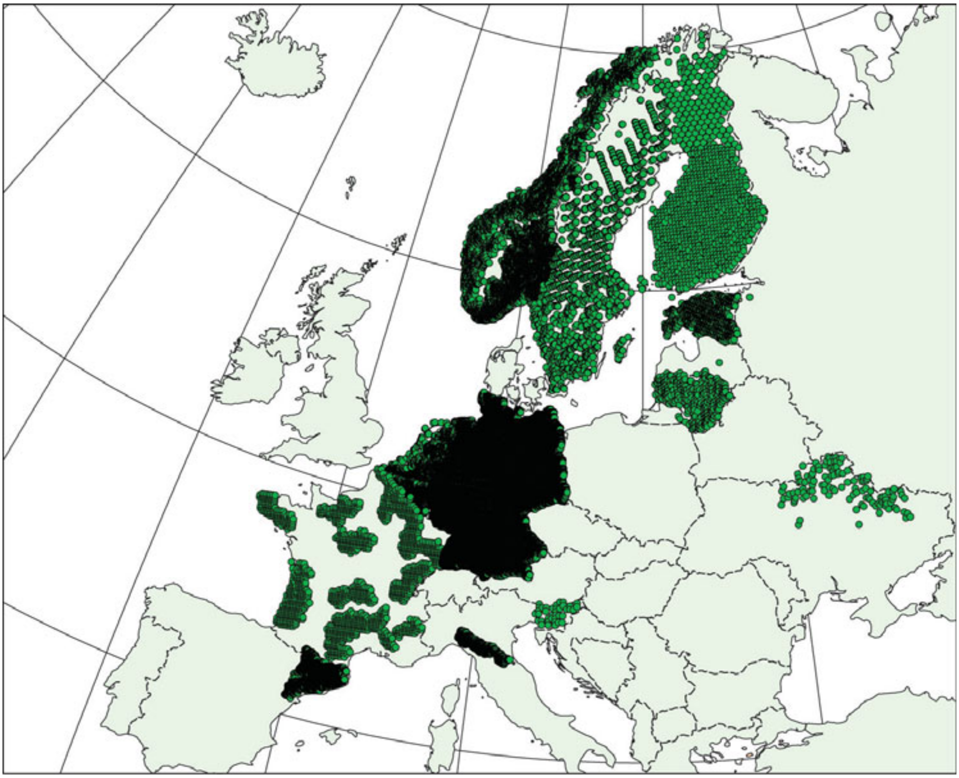

Fig. 13.1. The locations of the 229 000 plots in 14 countries for which data were received. Very recent Portugese data were also received.

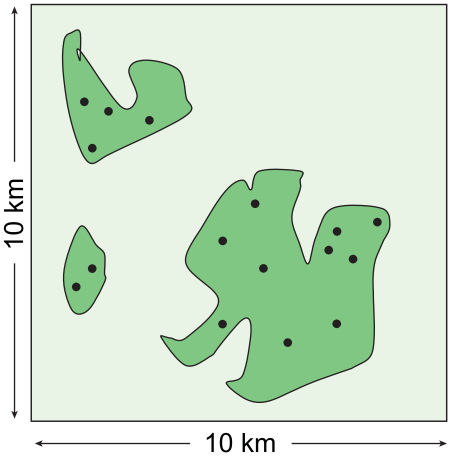

Fig. 13.2. One grid cell of 10 × 10 km with patches of forest (shaded) and the location of 16 randomly located forest inventory sample plots (dots).

Secondly, the stemwood data and increment need to be converted to the full carbon balance. For this we initialize the CO2FIX model for each plot (Masera *et al*., 2003). CO2FIX V.2 is a user-friendly tool for dynamically estimating the carbon sequestration of forest management, agroforesty and afforestation projects; it is a multi-cohort, ecosystem-level model based on carbon accounting of forest stands, including forest biomass, soils and products. Carbon stored in living biomass is estimated with a forest cohort model that allows for competition, natural mortality and mortality due to logging damage. Soil carbon is modelled using five stock pools, three for litter and two for humus. The dynamics of carbon stored in wood products is simulated with a set of pools for short-, medium- and long-lived products, and includes processing efficiency, reuse of by-products, recycling and disposal forms. For each plot, the measured height and increment are regressed on an extensive database of 1200 yield tables from across Europe. From the selected growth curve, increment is projected through time. To arrive at total tree biomass we rely on semi-dynamic biomass expansion functions similar to those given by Zianis *et al*. (2005).

In order to initialize the soil, the plot data are overlaid on the new soil C map (Baritz, 2007). The total carbon from the 1 × 1 km grids in the soil C map is fractionated over the five CO2FIX soil C pools.

Preliminary Results

Some preliminary results are given in Figs 13.3 and 13.4. Figure 13.3 shows the temporal development over time of the carbon balance of five randomly chosen

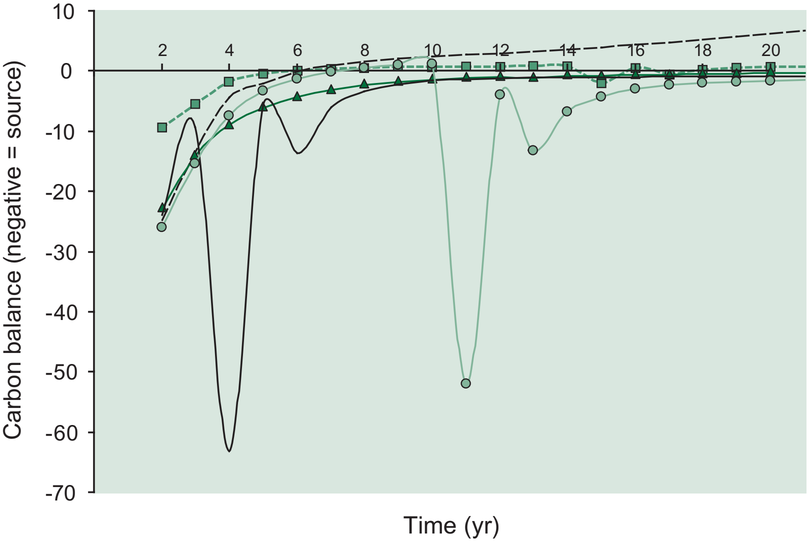

Fig. 13.3. Temporal evolution of the carbon balance – tC ha^{-1} yr^{-1} (forest biomass, soils and products) of five plots in Norway over the period 2000–2020.

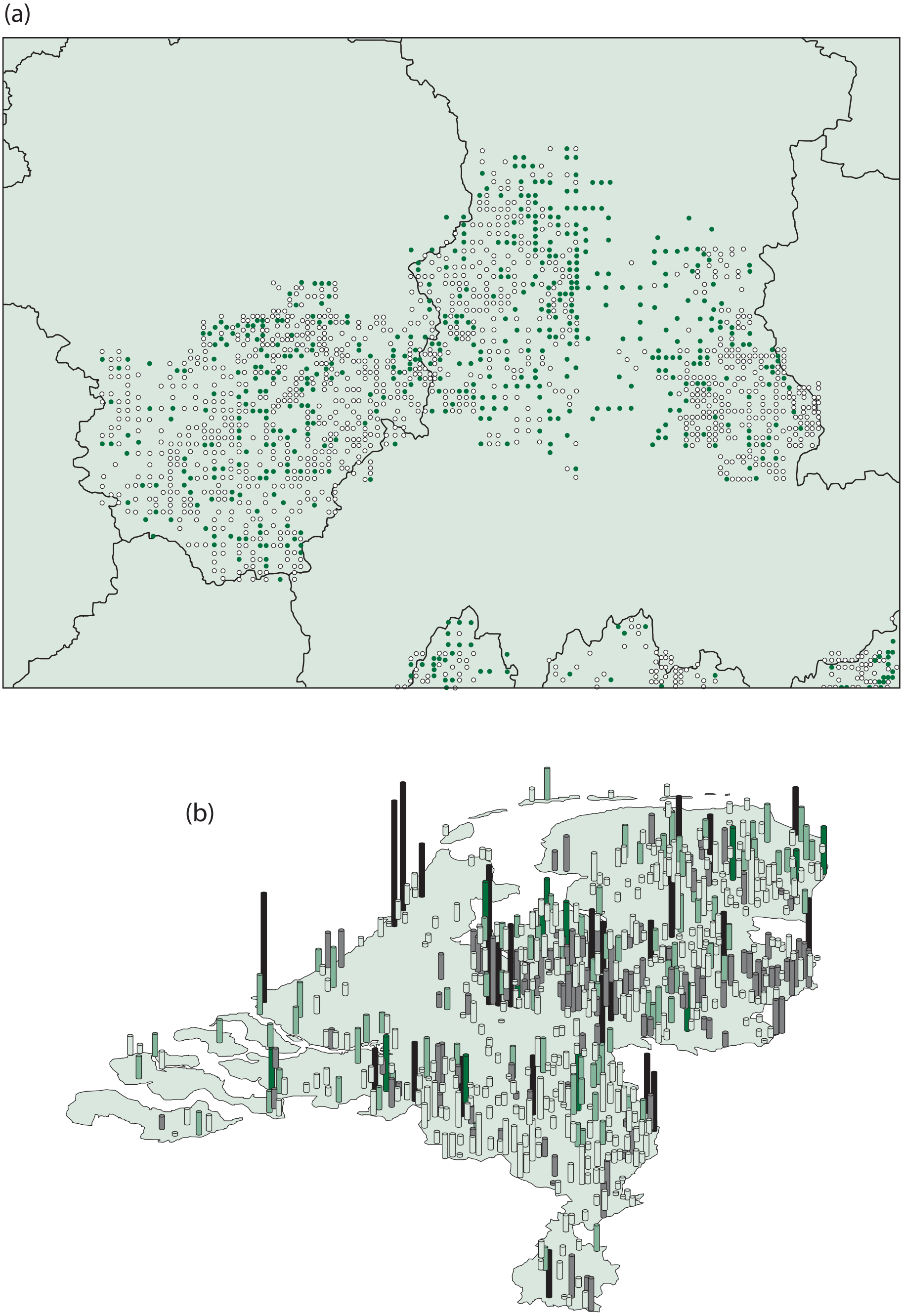

Fig. 13.4. Two examples of the high resolution carbon balance work. (a) Spatial distribution of the carbon balance per plot in Auvergne/Limousin in France in 2000 in flat view. Black and grey indicate that the plot acted as a source in 2000, green means it is a sink. (b) The same for The Netherlands in 3D view in 2000. The size of the bar indicates the size of the sink or source. Black and grey indicate that the plot acted as a source in 2000, green means it is a sink.

forest plots in Norway. Negative values (tC ha^{-1} yr^{-1}) represent flux of carbon from the forest to the atmosphere and positive values are sinks.

Figure 13.3 shows that all plots start with a rather large source of between 10 and 25 MgC $ha^{-1}yr^{-1}$. From analysis of the detailed output it appeared that in the soil initialization too large a fraction of total carbon was allocated to cellulose and hemicellulose, both soil pools that decay rapidly. This causes the overall carbon balance to remain negative for the first 5 to 10 years. Two plots show a large source in years 4 or 11 respectively. These plots were harvested (felled) in that year, and decomposing logging slash and wood products allowed a source to remain throughout the simulated period. From further analysis of the data of biomass recovery after logging it also appeared that regrowth (replanting or natural regeneration) in these clearfelled plots did not pick up fast enough.

Figure 13.4 then shows the spatial distribution of these sinks and sources in two other case examples: Auvergne/Limousin in France and The Netherlands in 3D view. Summations of results have so far only been made for The Netherlands (van den Wyngaert *et al.*, 2007) where it was assumed that the soil is in balance. In this case the model outcome gave very good results with a national level carbon sink (harvest deducted net biome production (NBP)) of 2110 $GgCO_2$ yr^{-1} in the period 1990–2000.

Discussion

To date, the results indicate that the approach is working reasonably well. Several tests have been carried out, but full country runs are only in a very preliminary state at present. Several problems still remain to be solved. One is to gain insight into the grid level uncertainty. Namely, national forest inventories are designed to give a reliable picture at the national level. However, if we use the few plots (usually between 5 and 25) in a 10 × 10 km grid cell, then the uncertainty will rise considerably. This will require further study.

The problem of countries for which we do not have the plot level data still remains. It will also be necessary to quantify the uncertainty in estimates of tree species distributions based on modelling of plot level data where available, and extrapolation for other countries.

The overlay on the soil map causes a strong fluctuation in the carbon balance at the start of the simulation. Fractionation of the total soil C over the five CO2FIX soil pools will also need further work.

Acknowledgements

We are greatly indebted to the national forest inventory institutes of Finland, Sweden, Norway, The Netherlands, Belgium, France, Italy (Emilia Romagna), Spain (Catalonia), Slovenia, Ukraine, Estonia, Lithuania, Portugal and Germany for providing plot level data. We thank the UK Forestry Commission, organizers of the OECD conference Forestry: a sectoral response to climate change'at Wilton Park in November 2006, for inviting us. Part of this work is based on the EU project: Carbo-Europe-IP.

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14 Forestry in Europe Under Changing Climate and Land Use

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Introduction

Global changes such as climate and land-use change may have significant effects on ecosystem services, and thus on people and society (Watson *et al.*, 2000; McCarthy *et al.*, 2001). The vulnerability of ecosystem services to such changes was assessed in the EU-funded research project ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling). For the forestry sector, among the key ecosystem services are wood production and the carbon sequestration potential of forests. Currently, forest growth seems to be increasing across most of Europe (Spiecker *et al.*, 1996; Karjalainen *et al.*, 1999), but besides climatic factors, nitrogen (N) deposition, carbon dioxide (CO_2) fertilization and changes in forest management are also possible causes for this trend. The impact of further changes in climate could be both positive or negative, depending largely on water availability (Kellomäki *et al.*, 2000).

Forest management has a significant impact on the current and future age–class distribution, and thus affects the development of volume increment. Changes in management and the amount of fellings have a decisive effect on the carbon balance of the forestry system (Kohlmaier *et al.*, 1995). At a larger scale, afforestation and deforestation can significantly alter the availability of forest resources and change the amount of carbon stored in forest ecosystems (Watson *et al.*, 2000). Therefore, approaches to forest management, changes in forest area and historic land use will influence the future development of forest resources in Europe.

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There are various methods available to project the impact of climate change and the increasing concentration of atmospheric CO_2 on forest growth. These range from simple experiments and statistical analyses based on historical or regional analogues of temporal and spatial variation in increment to more data-demanding biophysical and integrated models (Scholes *et al.*, 1998). Inventory-based methods are commonly applied to assess the forest carbon budget on a national to continental scale. In this study we integrate the effects of changes in wood demand, climate and land use on the European forest sector, combining a dynamic global vegetation model (LPJ-DGVM; Sitch *et al.*, 2003) with a large-scale, growth-and-yield model (EFISCEN; Sallnäs, 1990; Pussinen *et al.*, 2001). A consistent set of scenarios for wood demand, climate and forest area change were implemented to study the development of European forest resources over the 21st century. The development of forest resources was assessed for 15 European countries: Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK.

Methods

The Forest Information Scenario Model (EFISCEN)

The European Forest Information Scenario Model (EFISCEN) provided projections of the development of European forest resources under a broad range of climate, land-use and wood-demand scenarios from the present to 2100. EFISCEN is a large-scale scenario model, which uses forest inventory data as input and can be used to project the possible future development of forest resources on a European, national or regional scale. The inventory data used in this study cover almost 100 million hectares (ha) of forest available for wood supply and reflect the state of European forests in the mid-1990s.

Scenarios

The wood-demand, climate and land-use scenarios used in this study are based on the emission scenarios from the Special Report on Emissions Scenarios of the Intergovernmental Panel on Climate Change (Nakicenovic and Swart, 2000). Four ATEAM climate scenarios were used: the HadCM3 model (Gordon *et al.*, 2000) combined with four emission scenarios (a1Fl, a2, b1, b2; Schröter *et al.*, 2005). To incorporate climate change-induced growth changes, net primary productivity (NPP) values provided by the Lund-Potsdam-Jena global dynamic vegetation model (LPJ; Sitch *et al.*, 2003) were used to scale inventory-based stem growth in EFISCEN.

Each climate scenario was associated with consistent land-use change and wood-demand assumptions. The current (2000) wood demand was scaled with demand projections from Image 2.2 (Image Team, 2001) for each of the four emission scenarios, assuming that the relative change in felling levels would be constant throughout Europe. Wood demand increased in the a1FI scenario and to a lesser extent in the a2 scenario. In the b1 scenario, wood demand decreased, while it remained relatively constant in the b2 scenario (see Fig. 14.1a). Biofuels were assumed to come mainly from agricultural land, and the use of wood-based energy decreased except for the a1FI scenario, for which a slight increase was projected (Kankaanpää and Carter, 2004).

Relative forest cover change from the ATEAM land-use scenarios (Schröter *et al.*, 2005) was used to scale the current (2000) forest area available for wood supply in each of the EFISCEN regions. The development of forest area according to these assumptions is shown in Fig. 14.1b. The assumptions for the tree species chosen for afforestation were based on the storylines of the emission scenarios and the demand projections of Image 2.2 (Image Team, 2001). For the a1FI and a2 scenarios, it was assumed that coniferous species would be favoured for afforestation, as a result of high wood demand overriding environmental concerns in both scenarios. For the two scenarios that assume a high level of environmental consciousness, b1 and b2, it was assumed that only native tree species would be used for afforestation. In order to quantify the individual effects of management, climate and land-use change, additional model runs were conducted using the four management scenarios without land-use change, separately for current climate and the climate change scenarios.

Results and Discussion

For all climate scenarios under consideration, climate change resulted in increased forest growth. This effect was especially pronounced in northern Europe. In southern Europe, higher precipitation in spring and the projected increase in water use efficiency in response to the rising atmospheric CO_2 concentration mitigated the effects of increasing summer drought. Detrended climatic variation from the

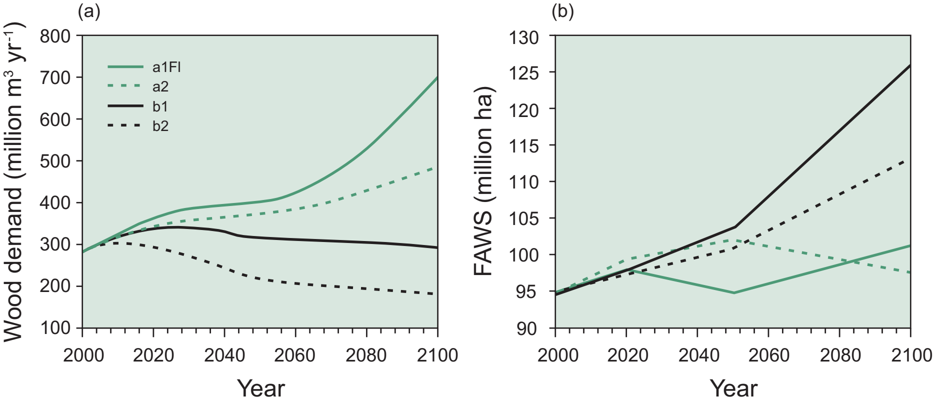

Fig.14.1. Development of (a) the wood demand and (b) forest area available for wood supply (FAWS) over the 21st century in the a1FI, a2, b1 and b2 scenarios.

20th century was used in constructing the climate scenarios for the 21st century. Therefore, a possible increase in climate variability and climatic extremes, potentially causing increased mortality rates, may be underestimated in our results. Initial average tree carbon stocks were 60 t ha^{-1}. Tree carbon stocks increased in all scenarios, depending on the rate of removals and forest area change. Average tree carbon stocks in 2100 ranged between 92 t ha^{-1} for the a1Fl and 132 t ha^{-1} for the b1 scenario.

Figure 14.2 presents the development of carbon stock changes over the 21st century for each of the emission scenarios considered, separately for the runs using current climate, climate change, and climate and forest area change. Under current climatic conditions, the tree carbon sink decreased in the a1Fl and a2 scenarios due to a large increase in removals. Towards the end of the 21st century, removals exceeded the increment in both scenarios, resulting in negative carbon stock changes. Removals were at a minimum in the b1 scenario and, as a consequence, the tree carbon sink was at a maximum. However, increment, and therefore the development of carbon stocks, is uncertain for this scenario because, due to the low wood demand, management is less intensive compared to the reference conditions for which the model was parameterized.

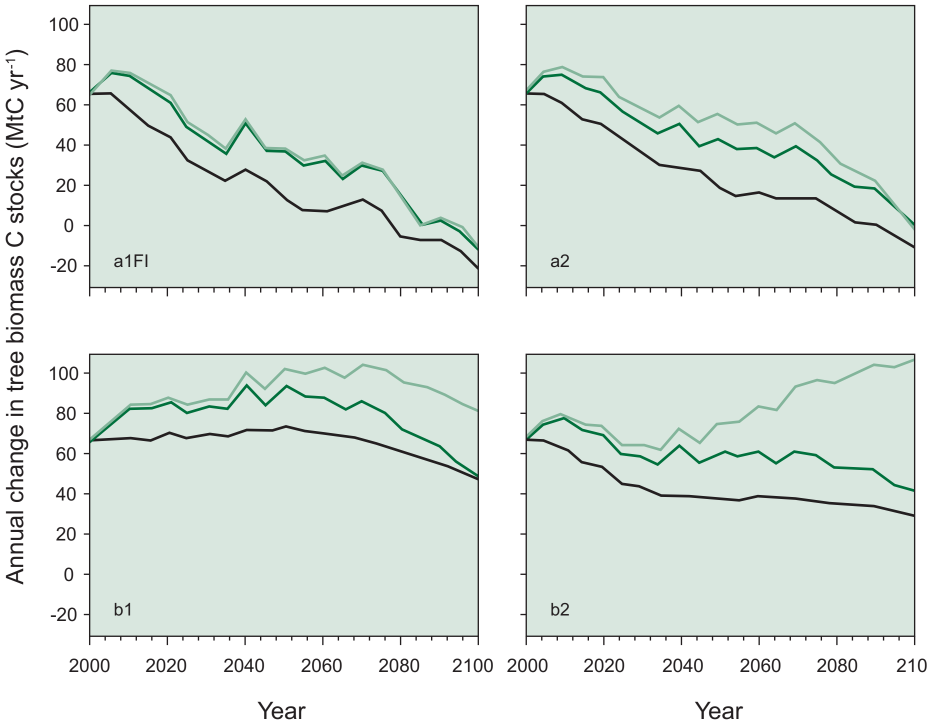

Fig.14.2. Development of the tree carbon stock changes (MtC yr^{-1}) over the 21st century. Data are the sum of the 15 modelled countries. Black line: current climate, only changes in wood demand; dark green line: climate change; light green line: climate and forest area change.

Climate change had a positive impact, enhancing the carbon sink in all four scenarios. Wood demand was not satisfied in the a1Fl scenario in the second half of the 21st century, but the increase in productivity resulting from climate change led to higher removals compared to the current climate. In the b1 scenario, the positive impact of climate change levelled off at the end of the 21st century because, as a result of the low demand for wood and increased growth in response to climate change, the proportion of old, dense and unproductive forests increased in comparison to the current climate scenario. Changes in forest area differed substantially between the four emission scenarios. In the a1Fl scenario, there was little change in forest area, whereas in the b2 scenario, forest area increased notably, creating a substantial additional carbon sink.

Figure 14.3 presents the relative changes in carbon stocks for the four emission scenarios, based on model runs in which changes in demand, changes in demand and climate, and changes in demand, climate and forest area were compared. When only differences in wood demand are considered, the increase in tree carbon stock ranges between 33% and 114%, depending on the amount of fellings. Climate change adds an additional tree carbon stock change of 23% −31%. The impact of land-use change depends on the extent and timing of afforestation, ranging between 2% in the a1Fl and 40% in the b2 scenario.

As is the case for any model analysis, uncertainties are associated with the models used, assumptions and scenarios. However, our results do give an indication of how forest resources might develop under a range of different, internally consistent, scenarios.

The study illustrates that wood demand plays a decisive role in the development of European forest resources. Under the scenarios investigated, European forests will remain a strong carbon sink for several decades, with the size of this sink mainly driven by wood demand. Despite regional variation,

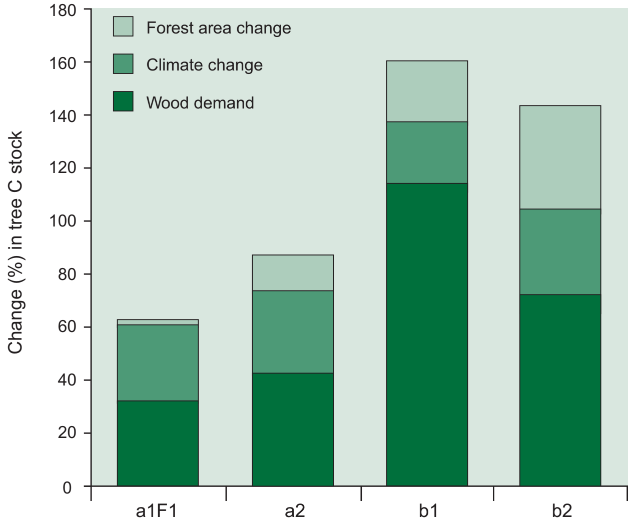

Fig.14.3. Percentage change in tree carbon stocks between 2000 and 2100.

climate change had a positive impact on forest growth in each of the scenarios analysed, with a consequent increase in timber availability. If management does not react to these changing conditions, many forests could become overmature, denser and more susceptible to biotic and abiotic damage. A further conclusion of the study is that afforestation measures have the potential to increase carbon stocks and increment in the long run, but large areas are needed to obtain significant effects.

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IV

Impacts of Climate Change on Forests: Options for Adaptation

> '… we predict, on the basis of mid-range climate warming scenarios for 2050, that 15–37% of species in our sample of regions and taxa will be "*committed to extinction*".'
>
> *Chris D. Thomas* et al.
> *Extinction risk from climate change*
> *Letter to Nature, volume 427, issue 6970, 145–147, 2004*

We are now observing climate change *impacts* to forests and forest soils and enhanced forest growth attributable to environmental change. Model predictions indicate that different species choices must now be made to allow a good fit between climate and forest stand in future. The speed with which adaptation can be achieved will have a direct influence on the severity of ecosystem damage. In an era of global environmental change no forest ecosystem can be regarded as being so remote or extensive that it does not require to be effectively monitored and managed, even where the principal objective is conservation of biodiversity.

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Soils and Waste Management: a Challenge to Climate Change

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Introduction

Concerns over global climate change have many entities within the agricultural community as well as outside interests questioning the contributions that agriculture is making to the problem and the role it might play in remediation. There is little doubt that agricultural wastes and manure can potentially contribute to greenhouse gas emissions either through respiration or anaerobic decomposition. It is also a known fact that natural soil processes contribute to climate change by emitting carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The extent to which the emission process can be offset or even reversed is related to tillage and residue management practices. The ultimate question comes down to identifying the environmental processes and management practices that will ultimately sequester carbon (C).

Many of these topics were discussed at an OECD (Organization for Economic Co-operation and Development) sponsored workshop, Soils and waste management: a challenge to climate change, at Gorizia, Italy on 15–16 June 2006. Presentations at the workshop, which will be published in a special issue of *Waste Management* during 2007, were grouped into categories that illustrate agriculture's responsiveness to addressing recognized waste issues and processes that accentuate greenhouse gas emissions. Comments herein summarize the discussions and options offered at the Gorizia workshop. The principal consideration was agricultural systems, but much is relevant to forestry, also especially at a time when integrated land use is increasingly being considered for environmental sustainability. In our presentation (Lynch and Schepers, 2007) at the workshop we highlighted several high profile papers recently published in the journal *Nature* which have generated conjecture within the scientific community (Bellamy *et al.*, 2005; Schulze and Freibauer, 2005; Keppler *et al.*, 2006; Lowe, 2006; Raghoebarsing *et al.*, 2006; Reich *et al.*, 2006; Thauer and Sharma, 2006). We argued that multi-disciplinary (including social science) approaches are needed to address the issues.

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Reasons for Concern and Opportunities for Improvement

Biological processes have a lot to do with global climate change because the feedback mechanisms to changes in agricultural management practices can either accentuate the problem or tend to reduce its impact. Relative to the effects of fossil fuel combustion on CO_2 emissions, it is commonly recognized that CH_4 emissions are around 25 times more harmful and N_2O emissions are slightly over 300 times more degrading to the environment. Before serious attention can be given to processes that might be considered for remediation of global temperature rise, it is important to understand the biological processes that are involved. Presentations at the Gorizia workshop emphasized many times that the root zone can serve as one huge buffer, a source for C and N losses, or a sink for sequestration of C and nutrients. Whether C is truly being sequestered (>100 years) or just moving towards a new equilibrium state remains a question. Along the way, changes in soil C status can have far-reaching affects on soil chemical, physical and biological processes. Understanding how these processes interact with production practices and weather offers a key to developing effective strategies and management practices to either minimize the negative impact of agricultural production on the environment or optimize practices to achieve sustainability (Fig. 15.1).

Food Processing Wastes

The fate of olive mill waste and meat meal waste was featured as two examples of the processing of by-products that are frequently incorporated into soil for

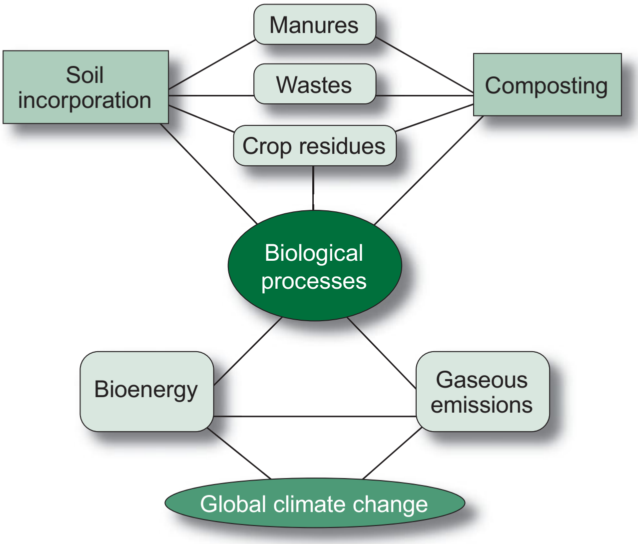

Fig. 15.1. Relationship between waste materials, crop residues, soil processes and management, and climate change.

disposal. Studies showed that the meat meal waste reached a peak degradation rate 1 to 2 days after incorporation, had a half-life of 3 to 4 days, and reached a baseline emission of CO_2 after about 10 days in soil at 20°C. During the first 10 days, 10 to 20% of the C added was lost as CO_2. In contrast to the meat meal waste that started mineralizing upon incorporation into the soil, the olive mill waste had an anti-microbial effect in soil because of the phenolic compounds it contained. Studies showed that fungi played a much larger role in degradation than bacteria and that nutrient availability from the waste was low.

Soil Processes

Soil organic matter represents the largest pool of C in our environment. As such, it has the potential to have a significant effect on greenhouse gas emissions. This includes N_2O in that N is a component of organic constituents in soil, be they in the form of microbes, invertebrates, degraded plant residues or recently added crop residues, manures and other wastes. Respiration is the key to biologically induced C losses from soil. Combustion of fossil fuels and renewable energy sources (biofuels) is essentially an accelerated form of respiration in that CO_2 is one of the products. The biology and chemistry of the soil environment is very complex and drives the adaptive capacity of the various types of soil microorganisms.

Predicting how the soil environment will respond to climate change is an evolving science that will take years to understand and validate, but soil respiration remains the key to C emissions from soil. Cultural practices that reduce the rate of net C losses do so by creating conditions that are adverse for respiration. These conditions include restricting access of specific nutrients to the microbes that degrade C compounds in soil. The key nutrient needed to enhance organic matter respiration is N in that the C:N ratio of many soil organisms is ~5:1 compared to residues that range from 20:1 to 100:1. At equilibrium, the C:N ratio in soil is ~10:1 and net mineralization on N only occurs with values <~30:1. Therefore, keeping the C:N ratio >30:1 leads to conditions for C accumulation. One strategy to promote C accumulation is to create physical conditions that prevent the soil organisms from thriving. Another strategy to reduce CO_2 levels in the atmosphere is to enhance the production of organic compounds via photosynthesis, which involves understanding how management systems impact plant and soil metabolic processes. Finally it should be noted that plant growth and soil biological activity cannot be viewed as being independent in that photosynthetic processes in plants generate root exudates that can trigger soil microbial activity and thus the degradation of organic matter. As such, a process that removes CO_2 from the atmosphere (photosynthesis) can also accentuate the emission of CO_2 by the respiration of soil microorganisms utilizing the rhizodeposition products thus generated (rhizodeposition being the loss of C as respiratory CO_2 and organic metabolites from roots). Learning to manage these various processes is the key to sustainability.

Management Practices

The fate of C compounds in the environment is largely related to how humans intervene in manufacturing and decomposition processes. It is not realistic to separate these processes in a holistic analysis of environmental processes and yet in terms of designing sustainable management practices it is appropriate to discuss the individual effects. Plants have been removing CO_2 from the environment since the beginning of their existence. Along the way, scientists have been striving to increase the efficiency of the photosynthetic process by creating crop cultivars that are higher yielding or perform better under adverse growing conditions. This includes the use of cover crops to produce vegetation and residues for livestock feed, grains, green manures. These efforts are a move in the right direction, but need to be coupled with soil management practices to have any lasting effects on CO_2 levels in the atmosphere. Again, this is because the soil embodies a huge pool of C that can be manipulated by management practices. At the individual field level, producers can reduce CO_2 emissions by reducing tillage and adopting no-till management practices. By doing so, producers reduce the consumption of fossil fuels and enable them to divert time required for tillage to more integrated management practices. Another benefit of reduced and no-tillage systems is water conservation, which has the potential to increase crop yields and reduce irrigation costs (both monetary and fossil fuel consumption).

As tillage systems change, soils approach a new state of equilibrium in terms of C content, both in terms of distribution within the root zone and temporally during the growing season. Considering the ever-increasing demand for energy and anticipated shortages of fossil fuels (either real or manipulated), there is a natural temptation to substitute renewable energy sources for fossil fuels sources. The net effect is that C compounds in grains, forage and residues that were once destined for animal consumption or to be deposited on the landscape are being considered for diversion to produce more readily consumable forms of energy like electricity, heat and ethanol. The economics and sustainability of the biofuel industry are openly debated. Certainly energy crops require high chemical inputs in terms of fertilizers and pesticides, and crop production can lead to destabilization of soil structures which are therefore potentially non-sustainable. By contrast, forestry systems have very low chemical inputs and do not destabilize soils, and with careful management which in most countries is tightly regulated leading to sustainability. Some of the same discussions are associated with C trading strategies between industries that emit CO_2 and agricultural interests that can potentially sequester C in soil or reduce the consumption of fossil fuels by adopting reduced tillage systems.

One of the major functions of agriculture and forestry is to either dispose of waste products from the rest of society or devise ways to utilize them in conjunction with the production of other products and operations. For example, the production of ethanol from grain generates a high protein by-product that can be combined with maize, wheat and soybean residues to produce an acceptable quality of feed for cattle. This approach to by-product utilization (brewers grain) generates a dilemma for producers in that they can either

(1) return the crop residues to the soil to enhance soil physical and chemical properties, (2) combine the residues with brewers grain to formulate livestock feed that will eventually result in the generation of manure, or (3) directly harvest the residue for production of ethanol or combustion to generate heat for other industrial processes. In one way or the other, agriculture is called upon to accept and utilize waste products, be they in the form of liquids (slurries of manure and processing wastes), solids (manures and ash) or gases (CO_2 and NH_3).

Manure Utilization

Concentration of animals and poultry within dedicated operations also results in the concentration of manure. Efforts to economize have resulted in increasingly larger operations, which complicate the problem of manure utilization and move it into the realm of disposal, eventually causing environmental problems. Three approaches for manure treatment were presented: composting, anaerobic digestion and land application. Composting was proposed as an economical way to reduce the volume and complement commercial fertilizers when applied to the land. Studies also showed that compost could induce soil-borne disease suppression, as well as improve soil physical properties such as increased water-holding capacity and reduced bulk density. Direct land application of manure is a viable option, but accessibility is limited to times when crops are not growing or at least short enough to be undamaged during application. Local regulations frequently require incorporation of solid manure or slurries, which further limits the time when manure can be applied without damaging crops. Swine and dairy operations often use large amounts of water to remove the manure from the vicinity of the animals. The associated lagoons provide a convenient way to store the liquid/solid combination until land is available for application, but the anaerobic conditions in the lagoon promote losses of CH_4 and various gaseous forms of N. A considerably more expensive approach to manure management involves biogas production through anaerobic digestion with subsequent application of the sludge to the land. Application of liquid manure components to land carries valuable nutrients but can also contain salts that can accumulate over time and thus degrade productivity.

Conclusions

In this brief summary of the soil processes in relation to waste utilization and their impact on climate change, little critical quantitative information is given. This is largely because it does not exist and what is needed is Life Cycle Assessment (LCA). Immediately prior to the Gorizia workshop, we attended a workshop on LCA for soils at the University of Surrey, UK. Information on the LCA Workshop website (www.soc.surrey.ac.uk/ias/reports/DEFNBEST-report.html) provides useful guidance on experimental methods for this.

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16

Impacts of Climate Change on Forest Soil Carbon: Principles, Factors, Models, Uncertainties

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Introduction

Recent global estimates of terrestrial carbon stocks indicate that soils contain more than three times as much carbon as the atmosphere (Field and Raupach, 2004; Davidson and Janssens, 2006). Moreover, except for the tropical zone, the largest amount of carbon (C) in forest ecosystems is stored below ground, i.e. in the soil (Fig. 16.1). In particular, large relative and absolute amounts of carbon are stored in ecosystems that are currently not forested, but may be afforested in the future (peatlands and permafrost soils).

With globally 68–80 GtC yr^{-1}, soil respiration represents the second largest carbon flux between ecosystems and the atmosphere (Raich and Schlesinger, 1992; Raich and Tufekcioglu, 2000; Raich *et al.*, 2002). This amount is more than ten

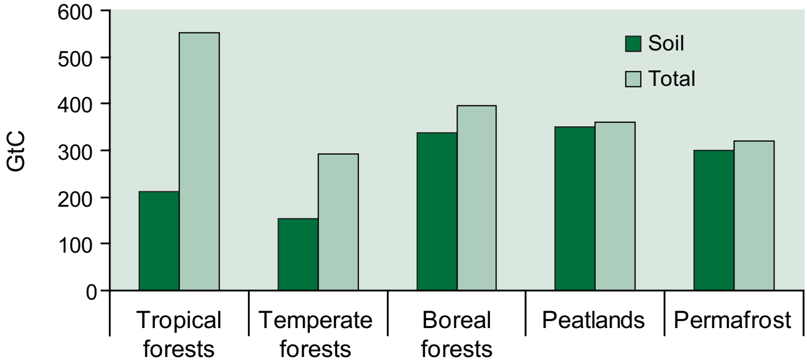

Fig. 16.1. Approximate global mean distribution of carbon within terrestrial ecosystems. The columns show C in soil (left) and total C in soil and vegetation (right). Except for tropical forests the majority of carbon is stored in the soil.

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times the current rate of fossil fuel combustion and indicates that each year around 10% of the atmosphere's carbon dioxide (CO_2) cycles through the soil. Thus, even a small change in soil respiration could significantly intensify – or mitigate – current atmospheric increases of CO_2, with potential feedbacks to climate change.

Moreover it has been repeatedly suggested that soil carbon sequestration is an important climate change mitigation strategy that can be used to 'buy time' while non-fossil fuel energy sources and conservation measures are implemented. For example Lal (2003) estimates the potential soil carbon sequestration at 30–60 GtC until 2050. On the other hand in this context it has to be noted that during the last millennia global soils have already accumulated large amounts of carbon, against which current additional sequestration potential appears tiny, while the amount of carbon that can potentially be lost again is considerable (Fig. 16.2). The vulnerability of soil carbon should thus receive at least as much attention as sequestration potentials, particularly when talking about forest soils. Moreover any strategy for sequestering carbon in vegetation biomass needs to be critically assessed with respect to its effect on soil carbon.

Hence it is of paramount interest how forest soil carbon reacts to climate change, and whether soil carbon sequestration or loss will be dominant under future regimes. The topic of climate change impacts on forest soil carbon relates most obviously and directly to the UN Framework on Climate Change and Kyoto Protocol, but with the functions of soil in the ecosystem it also relates to the UN Conventions to Combat Desertification and on Biological Diversity.

Analytical Framework: Direct and Indirect Effects of Climate Change on Soil Carbon

To avoid fundamental misunderstandings when discussing the effect of climate change on soil carbon, a clear distinction should be made about which level of

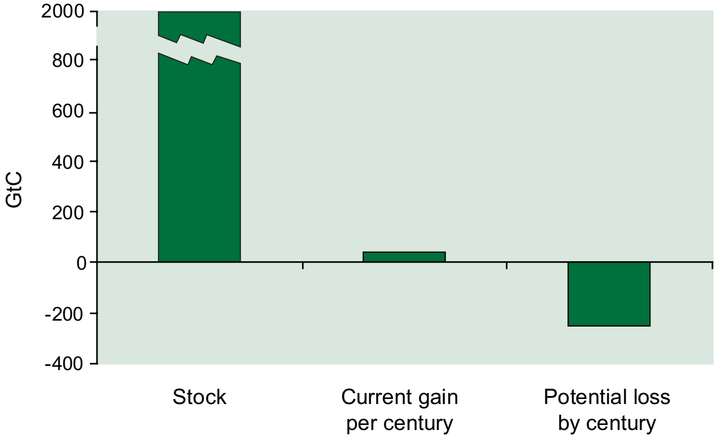

Fig. 16.2. Approximate current stocks of global soil carbon, compared with current carbon sequestration and potential loss per century. All numbers are approximations.

integration we are talking about (Fig. 16.3). At the lowest level of integration only direct effects on the decay of soil carbon are considered. Here, the stimulating effect of increasing temperature on microbial activity under most conditions will dominate and lead to a decrease of soil carbon. At the next level of integration, climate effects mediated through vegetation productivity and consequently carbon input into the soil (amount and quality) have to be considered. Finally, natural and human disturbances may also be influenced by climate, and in turn act on vegetation and soil carbon directly, but in a hardly predictable manner. This chapter concentrates on the first two levels of integration, but keeps in mind that the disturbance and management effect may well override more direct climate change effects.

Soil Carbon: a Balance between Primary Production and Decomposition

Fundamentally, any change in organic soil carbon will be caused by an imbalance between carbon input into the soil via primary production and losses via decomposition (and vertical and lateral transport) as indicated in Fig. 16.4. Any increase in primary production will ultimately tend to increase, while any increase in decomposing activity will tend to decrease soil carbon stocks. The various climate elements act on these two processes in non-linear and partly similar, partly contrasting ways, where saturating, exponential and optimum-type responses exist (Fig. 16.4). The final climate change effect will depend on how the delicate

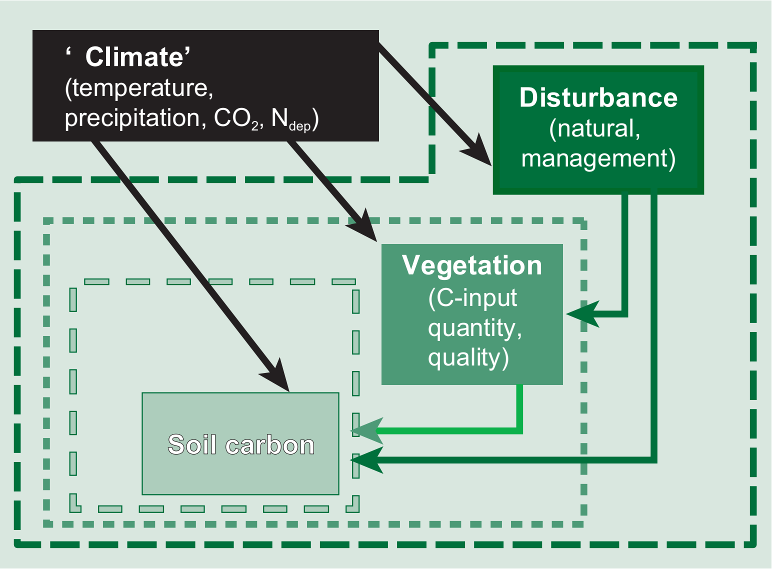

Fig. 16.3. Conceptual framework for separating direct climate effects on soil carbon stocks from effects at different levels of integration. When describing climate effects on soil carbon stocks it is important to define the level of integration.

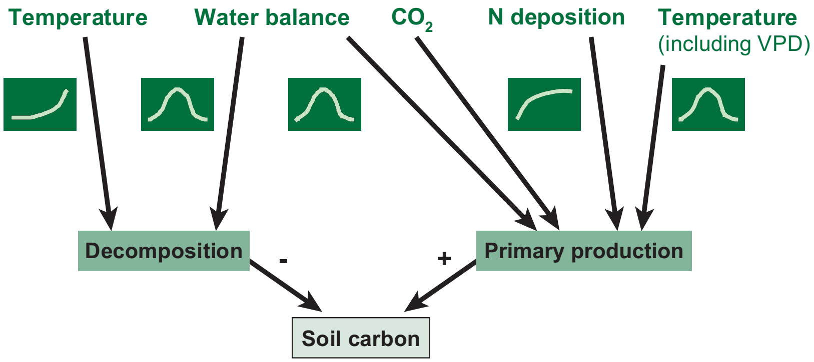

Fig. 16.4. Qualitative scheme for analysing the effect of climate change on soil carbon via control on decomposition and primary production.

balance between carbon input and loss changes. The situation is even more complicated since, in reality, there is also a mutual influence between these two. For instance decomposition influences vegetation productivity via release of nutrients. The following sections briefly discuss the individual factor effect and the joint effect predicted in a state-of-the-art dynamic global vegetation model (DGVM).

Impacts of Global Change on Photosynthesis and Carbon Inputs to Soil

Cold temperatures are the major factor limiting plant growth in high-latitude (Antarctic, Arctic, boreal, cool temperate) ecosystems. Rapid warming associated with increasing atmospheric greenhouse gas concentrations has already been observed in some high-latitude regions such as continental North America. Global warming is expected to increase the growth of existing boreal forests and to allow the northward spread of forests into areas currently occupied by tundra. This picture is complicated by the prospect of increased frequency of insect outbreaks and fires and by the collapse of forests into sedge- and grass-dominated areas in thermokarst (areas of permafrost melting and soil subsidence). In general, however, stimulation of plant productivity by warmer temperatures will increase plant litter inputs and soil carbon pools.

Precipitation trends will affect the ability of plants to respond to global warming. Although there is a high probability that average precipitation amounts will increase, global circulation models indicate considerable regional variability in predicted trends. At any given point on the Earth's surface, there is greater uncertainty about precipitation trends than temperature trends. The water balance is important for the ecosystem, i.e. even with unchanged precipitation ecosystems will experience more drought stress, since due to higher temperatures high evapotranspiration rates will occur.

A higher frequency of droughts, floods and violent storms will likely have a negative impact on long-term average carbon stocks, both below and above ground. Changes in weather are inherently abrupt, even at hourly and daily timescales, and ecosystems respond to these changes in a complex and non-linear fashion. For example, high mortality rates were observed after the 2003 heatwave.

Increasing CO_2 levels will increase plant productivity and thereby enhance the amount of C added to soils. This is partly a direct effect on photosynthesis and partly the result of higher water use efficiency. Plant stomata open less to acquire the same amount of CO_2, and water losses are reduced. Photosynthesis will saturate at a particular CO_2 level, which varies with the type of plant photosynthetic metabolism. However, as data from experiments with *in situ* field CO_2 enrichment studies become available, results suggest that the gains in productivity may be smaller than previous estimates, owing in part to limitations of soil nutrient availability. Conversely, there is considerable evidence that plants grown at high nutrient supply respond more strongly to elevated CO_2 than nutrient-stressed plants. Even given the likelihood that elevated CO_2 will increase plant productivity and plant litter inputs to soils, the magnitude and fate of this 'new C' is very much a matter of debate. One promising new approach for addressing this question is analysis of stable carbon isotopes. By following the fate of 13C-depleted CO_2 added at elevated levels (570 ppm) to beech–spruce model ecosystems in open-top chambers, Hagedorn *et al*. (2003) concluded that only a small fraction of new C inputs to soils will become long-term soil C.

Manufacture of nitrogen (N) fertilizers (e.g. ammonia production from N_2 gas and methane via the Haber process) and the oxidation of N_2 gas to N oxides (associated with high temperatures of fossil fuel combustion) have doubled annual inputs of plant-available N – a massive change in the global N budget. Increasing N deposition increases plant productivity on many sites where N is a limiting nutrient. As a general rule, soil N supply is often limiting in temperate and boreal forests and grasslands, while plant growth in tropical regions is limited by other elements. Where plant growth is now limited by N deficiencies, increased atmospheric N deposition and applications of fertilizer N may accelerate plant growth. This tends to increase plant litter inputs and enhance the carbon stock of the soil. Increased emissions of N oxides are a major contributor to acid loads in precipitation. Leaching of the highly mobile, negatively charged nitrate anion is accompanied by increased loss of metal cations such as magnesium, calcium and potassium. Losses of these essential mineral nutrients from plant canopies and soil can reduce ecosystem productivity and partly offset gains resulting from increased N availability.

Other Atmospheric Pollutants Tend to Reduce Ecosystem Productivity

Sulphur oxides released during combustion of fossil fuels – especially coal – are the major contributor to human-derived acid loading in many regions. While sulphur is an essential plant nutrient, pollutant loads in some regions vastly exceed plant demand and may in some cases reach levels that are directly toxic to plants. In addition to direct toxic effects, leaching of the sulphate anion is accompanied by loss of essential mineral nutrients from plant canopies and soils. Ground-level ozone is a serious and widespread pollutant. Current levels are high enough to reduce plant productivity in many industrialized parts of the world. For example, increased surface ozone concentrations may have caused grain yields to decline by 20% in some parts of Europe (Semenov *et al*., 1997). Trees in rural areas may be more susceptible to ozone damage than those in urban areas, where scavenging by nitrogen oxides limits damage (Gregg *et al*., 2003).

Impacts of Global Change on Soil Respiration and Carbon Outputs from Soil

Warmer temperatures are a strong stimulus for soil respiration. Warming increases litter turnover rates and may accelerate decomposition of carbon already stored in soils. Furthermore, while soil warming accelerates soil organic matter decay and CO_2 fluxes to the atmosphere, it also increases the availability of mineral nitrogen to plants, which may indirectly stimulate enough carbon storage in plants to compensate for the carbon losses from soils. Organic matter decomposition tends to be more responsive to temperature than photosynthesis, especially at low temperatures. Global circulation models predict greater increases in minimum than maximum temperatures, so the balance of respiration and production in winter may be significantly affected. Warming in winter will tend to stimulate respiration (carbon loss) more than plant production (carbon gain), resulting in a loss of soil carbon.

While there is considerable uncertainty about how climate change will affect regional precipitation trends, overall predictions are for increasing precipitation. There may be regions where increases in precipitation do not keep pace with temperature-driven increases in potential evapotranspiration. When soil is at or above its moisture holding capacity, soil respiration falls off rapidly, as evidenced by peat accumulations in wetlands. Soil respiration can be stimulated by wetting and drying, and changes in frequency and intensity of precipitation may have more importance for the fate of soil carbon stocks than trends in mean annual precipitation.

Desertification should not be thought of as a process wholly controlled by water inputs in precipitation. In addition to climatic factors, desertification is influenced by unsustainable land use (such as overgrazing or overharvesting of fuelwood), physiological responses of vegetation to climatic variation, and changes in soil physical properties that influence infiltration and erosion. The higher frequencies of extreme weather events (drought, intense rainstorms, high winds) predicted by climate models are likely to act in concert with these other factors to worsen the problem of desertification. Lal and Bruce (1999) estimate that total soil organic carbon displaced by erosion annually is approximately 0.5 Gt, of which 20% may be emitted into the atmosphere (the remainder is relocated on the landscape). Afforestation activities in arid regions will become more feasible with rising atmospheric CO_2 levels, given their positive effect on the water use efficiency of photosynthesis (Grunzweig *et al*., 2003).

Current Predictions of Process-based Models

The separate and joint effects of the factors discussed above from local to global scale can probably only be addressed via a mechanistic modelling approach, where current process understanding of the subsystems and interactions between subsystems are implemented in a single ecosystem model operating spatially distributed at global scale. On the separate effects of temperature and CO_2, ecosystem models tend to agree. The warming effect will lead to decreasing soil carbon while increasing levels of CO_2 will lead to increased carbon stock via increased productivity (Jones *et al.*, 2005). The joint effect of both of these main factors is not unequivocal as can be seen in the prediction by the Lund-Potsdam-Jena model (LPJM)–DGVM driven by scenarios from four different GCMs (Plate 5). The net effect depends both on the timescale (not shown), the predicted climate change and, most importantly, the biome under consideration. In general, most global models predict that the current sink of carbon, introduced by increased primary production via CO_2 and temperature effects, will strongly decline or revert into a source over time, since the stimulating effects on productivity saturate while the decomposition rates still increase owing to increasing temperatures (Friedlingstein *et al.*, 2003). Until 2100, the LPJ model predicts a future carbon sink in high-latitude and high-altitude ecosystems, while carbon sources integrated over the 21st century are anticipated for the boreal and temperate zones (Schaphoff *et al.*, 2006). In the tropics the response is heterogeneous both between continents and climate scenarios. Hence, the tropical carbon balance response that was one major driver of the terrestrial positive carbon feedback in the Hadley coupled climate model (Cox *et al.*, 2000). It is important to note, however, that a number of relevant ecosystem and soil processes are still not included in the global process-based model (Fig. 16.5).

Factor or mechanism	Likely effect on soil C if process represented
► CO_2 effect / interactions with the N cycle	↓
► Permafrost dynamics	↓
► Extreme events	↓
► Temperature sensitivity / interactions with H_2O cycle	↑
► Interactions with biota and soil–vegetation feedback	↕
► Dynamics of the forest floor and deeper soil horizons not accounted	↕

Fig. 16.5. Factors and mechanisms neglected in current global vegetation models and their likely effect on predicted soil carbon stocks when included.

1. Interactions and limitations of vegetation productivity by the nitrogen cycle are either unrepresented or weakly represented in these models. Hence, the CO_2 fertilization effect predicted by the models is likely to be overestimated. With adequate representation lower levels of productivity are likely (saturation effect) and thus less soil carbon storage.
2. The large carbon reservoirs in permafrost soils are not represented, as well as the permafrost thawing dynamic itself. If these are included large losses of these carbon pools due to thawing and warming are likely to be predicted. Hence, a potentially enormous positive feedback of the carbon cycle is neglected.
3. Extreme events and lag- or carry-over effects are not treated. It is likely that increased mortality will occur with more frequent extreme events like the 2003 heatwave or storms, reducing productivity and adding decomposing material to the soil (Ciais *et al*., 2005; Reichstein *et al*., 2007). Over the short term, soil carbon will increase through this debris, but if vegetation productivity is decreased, on average a long-term decline in soil carbon will occur.
4. Some studies indicate that the temperature sensitivity of soil and ecosystem respiration might decline when it becomes drier, contrary to what models predict (Reichstein *et al*., 2007). This effect would dampen the positive feedback of soil carbon to warming and thus lead to relatively higher predicted soil carbon pools.
5. Interactions with soil biota, soil vegetation feedback and dynamics of the forest floor and deeper horizons are not represented; they too are hardly understood (Fontaine *et al*., 2004). Hence, these factors might increase or decrease predicted carbon stocks, but they have a potential to amplify the effects of other factors (e.g. through positive feedbacks with soil degradation).

Conclusions

A simple but important point to keep in mind is that forest soils already contain a large amount of carbon that is highly vulnerable. Hence the need for protection should be emphasized strongly in comparison to carbon sequestration in forest soils. Any additional carbon sequestered in soils is subject to loss, again due to dynamic equilibria.

The overall effect of climate change on forest soil carbon is difficult to predict, since it depends on the balance between primary productivity and decomposition. Models tend to see an overall negative direct effect of temperature-related climate change on forest carbon stocks, but the effect of total climate change (including rising CO_2 concentration) depends on region and timescale. The uncertainties owing to climate predictions and to model structure are large. It is likely that improved models will predict stronger overall losses of soil carbon within the next century than current models do. A factor which is hard to predict but considered in related chapters of this book is the future development of forest management under climate change; see for example Solomon and Freer-Smith (Chapter 19) and Broadmeadow and Carnus (Chapter 26).

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17

Direct Effects of Elevated Carbon Dioxide on Forest Tree Productivity

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Introduction

The concentration of carbon dioxide (CO_2) in the atmosphere has risen by approximately 35% since the preindustrial era to approximately 380 ppm now, and is continuing to rise by 1–2 ppm per year. This rate of CO_2 increase in the atmosphere is unprecedented in the recent past, for at least 2 million years. Despite the thousands of papers that have been published on the impacts of CO_2 on forest trees and forest ecosystems, how forest trees (the largest terrestrial carbon pool on Earth) will respond to the continued rise in atmospheric CO_2 is still largely unknown (Körner *et al.*, 2005). This is partly because the vast majority of research on the effects of elevated CO_2 has been carried out on small trees in laboratory or chamber conditions, in which the artificial nature of the exposure conditions make predictability to forest conditions questionable. Over the past decade, however, the development of Free-Air-CO_2-Enrichment (FACE) technology has allowed the exposure of entire forest stands of any age '*in situ*' with unaltered climatic conditions, realistic competitive interactions, and with natural pest interactions (Karnosky *et al.*, 2001; Plate 6). In this chapter, we examine recent results from FACE experiments that have addressed the question of rising atmospheric CO_2 effects on forest productivity and we highlight remaining major knowledge gaps.

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Forest productivity drivers

The question remains as to whether or not forest productivity will change as CO_2 rises in the atmosphere. Since most forest trees are not CO_2-saturated, photosynthesis has generally been shown to increase in elevated CO_2. While some down regulation has been reported under elevated CO_2, long-term FACE studies have not detected any major photosynthetic acclimation (Karnosky *et al.*, 2003; Liberloo *et al.*, 2006). Another key factor driving forest productivity is the leaf area carried by the trees. Leaf area index (LAI), a common measure of leaf area in forest stands, has been generally enhanced by elevated atmospheric CO_2 (Karnosky *et al.*, 2003, 2005; Liberloo *et al.*, 2006) in young stands but not in older stands (Asshoff *et al.*, 2006). The duration of foliage, the time from bud break to leaf abscission, also appears to be sensitive to elevated atmospheric CO_2, but responses have been variable from no effect (Asshoff *et al.*, 2006; Moore *et al.*, 2006) to a strong stimulation of leaf duration, principally by delayed senescence (Karnosky *et al.*, 2005).

Forest productivity

The individual drivers of forest productivity have shown considerable variability by species, clone and study. A recent comparison of four long-term forest FACE studies across two continents showed a highly conserved response with an enhancement of net primary production (NPP) at 560 ppm CO_2 by 23.2%, across a broad range of sites (Norby *et al.*, 2005). The authors attributed the response to increased light absorption as a result of greater LAI at the low end of the productivity scale and to an increased light-use efficiency at the sites with high productivity and LAI (Norby *et al.*, 2005).

Modifying Factors

Genetic variation

A wide range of inter- and intraspecific variability in response to elevated atmospheric CO_2 has been found in the forest FACE studies (Table 17.1). For example, in the Rhinelander study in northern Wisconsin, paper birch (*Betula papyrifera*) is the most responsive species to elevated CO_2 followed by trembling aspen (*Populus tremuloides*), while sugar maple (*Acer saccharum*) has shown no detectable stimulation in photosynthesis or growth during the 9 years of the experiment (Karnosky *et al.*, 2003, 2005). A similar range of variation in growth responses has been documented within a single species for trembling aspen (Karnosky *et al.*, 2005). The wide range of variation in responses suggests that forest community change is likely to occur as atmospheric CO_2 rises and some species and genotypes are favoured over others.

Recent developments in quantitative genetics and molecular biology are allowing detailed studies to be carried out to understand the genetic variation in

Table 17.1. Recent forest productivity studies in FACE experiments.

Species	Start age (years)	Study duration (years)	Measure	Enhancement (%)	Reference
Populus tremuloides	0	7	Total biomass	25	King *et al.*, 2005
Populus tremuloides/ Betula papyrifera	0	7	Total biomass	45	King *et al.*, 2005
Populus tremuloides/ Acer saccharum	0	7	Total biomass	60	King *et al.*, 2005
Populus tremuloides	0	7	Above-ground volume	5 to 60	Karnosky *et al.*, 2005
Betula papyrifera	0	7	Above-ground volume	68	Karnosky *et al.*, 2005
Acer saccharum	0	7	Above-ground volume	0	Karnosky *et al.*, 2005
Populus spp.	1 (coppice)	3	Above-ground biomass	29	Liberloo *et al.*, 2006
Liquidambar styraciflua	10	3	Net primary production	21	Norby *et al.*, 2002
Pinus taeda	14	8	Basal area increment	13 to 17	Moore *et al.*, 2006
Carpinus betulus	∇ 100	4	Basal area increment	–13 to + 13	Asshoff *et al.*, 2006
Fagus sylvatica	∇ 100	4	Basal area increment	5 to 50	Asshoff *et al.*, 2006
Quercus petraea	∇ 100	4	Basal area increment	–2 to 13	Asshoff *et al.*, 2006

responses to elevated CO_2. Carbon dioxide responsiveness seems to be controlled by small changes in the expression of relatively few genes, although it is likely that these genes may be of adaptive significance and provide targets for future optimized tree breeding as climate change progresses (Gupta *et al.*, 2005; Taylor *et al.*, 2005). Studies of genetic variation in a hybrid of *Populus trichocarpa* × *P. deltoides* has allowed tree growth responses to elevated atmospheric CO_2 to be linked to specific linkage groups as quantitative trait loci (QTL; Ferris *et al.*, 2002; Rae *et al.*, 2006). For example, QTL for above- and below-ground growth stimulations in elevated CO_2 are now resolved at the level of the genome in poplar (Rae *et al.*, 2006). Using a combination of QTL analysis with rapidly developing genomic approaches, it is now possible to link these traits to specific regions of the poplar genome sequences, identifying genes of adaptive significance under future conditions of higher CO_2 concentrations.

Age

The majority of the forest FACE experiments have been conducted on trees ranging from 1 to 15 years in age. These studies have resulted in an increase in height and diameter growth, on average, of 11–16% (Kubiske *et al.*, 2006) with a mean increase in NPP of about 22% (Norby *et al.*, 2005). Particularly responsive species such as poplars and birches can have biomass increases of 30–40% (King *et al.*, 2005; Scarascia-Mugnozza *et al.*, 2005; Liberloo *et al.*, 2006). Interestingly, there appear to be no allometric shifts caused by elevated atmospheric CO_2 as root/shoot ratios remain relatively constant (King *et al.* 2005; Liberloo *et al.*, 2006). While these observations on young stands are particularly valuable for predicting the ability of developing young forest stands and plantations to sequester carbon under rising atmospheric CO_2, we cannot yet readily predict how older forest trees will respond from these studies.

Recently, studies of mid- to older age forest stands (Körner *et al.*, 2005; Asshoff *et al.*, 2006) suggest that these older trees do not respond to elevated atmospheric CO_2 to the extent that younger trees do. However, since the species were different to those highly responsive species summarized by Norby *et al.* (2005), it is not possible to make a direct comparison between these studies of younger versus older trees. Since the older tree studies were done on a very limited number of trees, subjected to a step-wise increase in atmospheric CO_2, it is also not possible to extrapolate these studies to all forest ecosystems and interpret their response to the gradual increase in CO_2 that they will experience over the coming decades. Clearly, this question of CO_2 responsiveness as trees age remains an important, but unresolved, research question.

Climate

It has become very clear from the FACE experiments that the responsiveness of relative growth rates to elevated atmospheric CO_2 varies from year to year and that this variation is largely controlled by climatic conditions such as temperature, rainfall (Moore *et al.*, 2006) and incident photosynthetically active radiation (PAR; Kubiske *et al.*, 2005). The largest response of basal area increment to elevated atmospheric CO_2 in loblolly pine (*Pinus taeda*) occurred in years with the highest vapour pressure deficit (Moore *et al.*, 2006). For aspen, PAR and temperature during peak current year growth periods (i.e. July) and peak bud development periods (October) controlled 20–63% of the annual variation in response to elevated atmospheric CO_2 (Kubiske *et al.*, 2005).

Air pollution

While CO_2 is rising in the atmosphere globally, other air pollutants are rising regionally across large areas in the northern hemisphere. Thus, large areas of the Earth's forests will be facing exposure to co-occurring elevated CO_2 and elevated air pollutants (Karnosky *et al.*, 2001). One of the most pervasive air pollutants is tropospheric ozone (O_3) which is common downwind of major metropolitan areas around the world. The Rhinelander FACE experiment has shown that relatively moderate levels of O_3, similar to those that already occur over vast areas of the world's forests, can negate forest productivity enhancement induced by elevated atmospheric CO_2 (Karnosky *et al.*, 2003, 2005; King *et al.*, 2005; Kubiske *et al.*, 2006). As the IPCC has identified a rapid growth in background O_3 levels around the world, the impacts of this toxic pollutant must be factored into models of future forest productivity under rising atmospheric CO_2.

Nutrients

It has been suggested that soil fertility may constrain carbon sequestration potential in forest trees growing under elevated atmospheric CO_2 (Oren *et al.*, 2001). Whether or not, and at what point in the life cycle of a forest, nutrient limitations will start to occur for forest ecosystems growing in enriched atmospheric CO_2 remains an intriguing question (Moore *et al.*, 2006). Interestingly, regular nitrogen (N) additions to the three poplar species in the EUROFACE elevated CO_2 study in Italy resulted in little or no change in the response to elevated atmospheric CO_2. One possible explanation is that the EUROFACE study was developed on an agricultural soil with high N (Liberloo *et al.*, 2006).

Conclusions

Most tree species are not CO_2-saturated at current atmospheric CO_2 concentrations. Thus, it has long been predicted that forest tree carbon uptake rates will increase, leading to more productive forests as atmospheric CO_2 concentrations continue to rise. However, recent studies in open-air exposure facilities suggest that elevated CO_2 effects on forest productivity are not readily predictable and can vary largely, depending on tree species, age and co-occurring stresses.

The past decade of FACE experiments has greatly refined the knowledgebase regarding the effects of elevated atmospheric CO_2 on forest tree productivity.

However, many questions remain. In this brief review, we have highlighted the following research gaps:

- A robust quantification of the CO_2 responsiveness of older forest ecosystems and of the potential for nutrient limitations to reduce forest productivity for forests exposed to elevated atmospheric CO_2 is still remaining.
- The extent to which forest productivity will be affected by interactions between elevated CO_2 and other variables is yet unclear; for example, little is known about $CO_2 \times$ temperature, $CO_2 \times$ drought, and $CO_2 \times$ forest pest and pathogen interactions. New large-scale experimentation will be required to address these questions.
- More research is necessary to identify adaptive genes of likely significance in the changing climate. Breeding and selection programmes for forest trees should begin to integrate these genes identified from genomic responses of trees to elevated CO_2 into improvement programmes.

- Almost no research has been done under FACE conditions for tropical forests, which represent a large terrestrial carbon sink in the southern hemisphere.

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18 Impacts of Climate Change on Temperate Forests and Interaction with Management

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Introduction

Forest ecosystems are characterized by a long response time to environmental changes. In that respect, two important features of climate change, its rapidity and globality, will require careful consideration. Due to their unequal longevity, population fragmentation and variation in life history traits (e.g. reproduction, dispersal), terrestrial species have a large range of potential for genetic adaptation. However, tree species have less potential to respond to changes on the timescale of a few decades than insects, fungi and microbes, including pathogens.

Another important characteristic of climate change will be its spatial variability. Recent modelling studies at the subregional level (Gibelin and Déqué, 2003) show that changes in precipitation and temperature regimes vary at the subregional scale, e.g. between the south and north of Europe. Since the geographical limits for many tree species are shaped by climate constraints such as temperature and drought, a change in climate can have a dramatic and asymmetric effect especially at the margins of natural areas, e.g. removing low

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temperature limitations towards the poles while increasing water deficits and high temperatures at lower latitudinal limits.

These changes can potentially affect tree species directly as well as indirectly through local site characteristics that control the availability of resources (Medlyn and Dewar, 1996). Assessing these effects on tree and stand functioning therefore requires a quantitative description of changes in the variables of interest at the local level. In this review, we summarize the results of predictions based on 50 × 50 km grid climate scenarios, and we analyse the interactive effects between management scenarios and site fertility on forest growth and carbon balance (Loustau *et al.*, 2005), potential habitat areas for tree species and insects and areas at increasing risk to pathogen infection (Bergot *et al.*, 2004; Desprez-Loustau *et al.*, 2007). We have implemented this simulation analysis over the western European Atlantic area, corresponding to the metropolitan area of France, that is characterized by a high diversity of biogeographic zones, management practices and tree species.

Climate Scenario

The French national meteorological office Météo-France atmospheric model ARPEGE/Climate (3.0) has been used to simulate present climate and 21st century climate through a 140-year numerical experiment (Gibelin and Déqué, 2003). The greenhouse gas and aerosol concentrations were prescribed by the so-called IPCC-B2 scenario (Houghton *et al.*, 2001). The ocean surface temperatures are provided by a model with a coarser resolution coupled to an oceanic water circulation scheme (Royer *et al.*, 2002). The radiative forcing scheme includes four greenhouse gases: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbon (CFC), in addition to water vapour and ozone, and five aerosol classes (land, marine, urban, desert and sulphate, respectively). The model predicts an increase in temperature reaching +4°C in summer over southwestern Europe and a shift in seasonal precipitation from summer to winter by 50 mm together with significant subregional variations.

Climate Potential Areas: Moving Poleward

Using botanical inventory data observed by the National Forest Inventory, empirical models relating the frequency of a given species to climate parameters such as minimum and maximum temperature, monthly precipitation and Penman's potential evapotranspiration were established and used for predicting the change in potential habitat areas under the climate scenario considered. This approach predicts a dramatic change in the geographical distribution of potential areas for tree species, with an extension of the southern temperate and Mediterranean species by 150 to 250 km northwards by 2100, together with a similar recession of most oak species, silver fir and beech at their southern edges (Plate 7). These predictions are consistent with observations of decline of some beech and Scots pine forests at their southern margins, e.g. in plains of southern France and the southern Alps.

Phenology

The phenology of vegetation is a major component of forest ecosystem productivity (Loustau *et al.*, 2005) and influences the annual balance of energy and gas exchange by forest ecosystems. Although current patterns can be estimated from satellites, we still lack the ability to predict accurately and widely future trends in the response of phenology to climate change because leaf phenology and its intra- and inter-population variability are difficult to parameterize. While progress has been made in modelling, the physiological bases for the control of environment on tree phenology are far from understood. The observed changes in tree phenophases during the past decades show that leaf unfolding, flowering, fruit ripening and leaf colouring will shift in the next few decades to earlier dates than those presently observed. A recent review on the variability of leaf unfolding dates in major forest trees shows that, on average, this has been advancing at a mean rate of 2.9 days per decade since 1950 in tree species from the temperate zone, with some species variation (Chuine *et al.*, 2007).

If changes in phenology remain linear with warming, using present trends we can estimate that leaf unfolding should advance on average at a rate of 5.4 to 10.8 days per decade over the period 2000–2050. Thus, by 2050 leaf unfolding of forest trees could occur on average 27 to 54 days earlier than at present. Such a change would have major consequences on forest productivity and on the specific species composition of forests over a given area. A few species, with chilling requirements, would be delayed by a warming climate. However, the dual action of temperature on phenology (i.e. the action of cool temperature to break dormancy followed by the action of warmer temperature promoting cell growth during quiescence) should lead to a non-linear response of phenological change to warming.

Forest Growth and Biogeochemical Cycles

We used biophysical models such as CASTANEA (Dufrene *et al.*, 2004), GRAECO (Loustau *et al.*, 2001) and the large scale ORCHIDEE model (Krinner *et al.*, 2005) for simulating the annual carbon and water balances and wood production of forests averaged over complete forest rotations. Several management scenarios and a range of site conditions were considered.

The models predict a slight increase in the potential forest production until 2030–2050 followed by a plateau or a declining phase 2070–2100 sensitive to geographical variation, with the northern part of the temperate zone being more beneficial to wood production than the southern temperate and Mediterranean zones. In the southern temperate and Mediterranean forests where the largest increase in the growing season water deficit occurs, the CO_2 enhancement of gross primary production (GPP) was overshadowed by drought impacts. The changes in forest production, as predicted for different forest management options and site conditions, are explained by the counterbalancing effects of rising CO_2, water deficit and the fact that ecosystem sensitivity to climate decreases with age. The shorter rotations with high production rates and low standing stock were more affected, positively or negatively, than long rotations characterized by larger standing biomass and low productivity (Fig. 18.1). This interaction between climate, CO_2, nitrogen (N) and water availabilities and management regime is an important outcome of our modelling analysis. Carbon dioxide is relatively more limiting under fertile conditions, e.g. for stands following their curve of maximal productivity. Conversely, the productivity in poorer and drier sites is constrained by limiting factors that may remain unchanged over the period examined. The response of the managed forest is dominated by the sensitivity during the juvenile phase, where the standing biomass and autotrophic respiratory losses are minimal while productivity is relatively high. The impacts of climate tend to occur before canopy closure providing there is some opportunity to increase carbon and nutrient capture through canopy and root expansion. Conversely, the relative weight of old stands is larger in unmanaged forests. After canopy closure, the stand leaf area index (LAI) is increasingly constrained by limiting resources such as water and

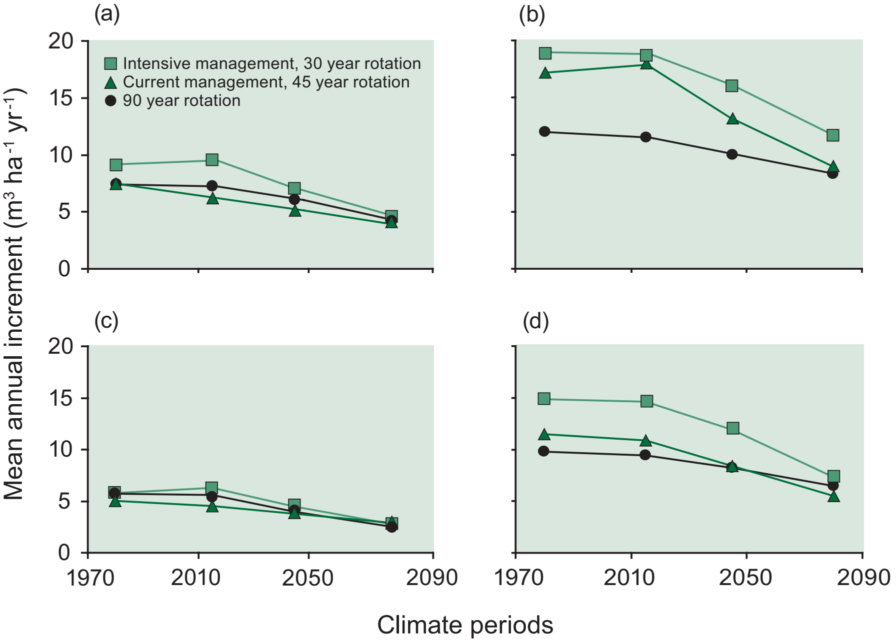

Fig 18.1. The interaction between climate change, local site conditions and the management regime, as illustrated for even-aged maritime pine stands in southern France. Each value is the annual increment of wood averaged over an entire rotation (MAI in m^3 ha^{-1} yr^{-1}) as modelled for three management scenarios, four climate periods (1980 to 2080) and different site conditions as follows: (a) poor sites characterized by foliar N at or below 1.0 gN 100 g dry matter $^{-1}$ and soil water holding capacity at or above 150 mm; (b) rich sites characterized by foliar N at or above 1.5 gN 100 g dry matter $^{-1}$ and soil water holding capacity at or above 150 mm; (c) poor site characteristics (N at or below 1.0 g N 100 g dry matter^{-1}) and soil moisture at or below 75 mm; (d) rich sites (N at or above 1.5 gN 100 g dry matter $^{-1}$) and low soil moisture capacity (75 mm).

nitrogen (Magnani *et al.*, 2000; Delzon *et al.*, 2004), stand productivity decreases while the standing biomass stock increases continuously.

In terms of the geographical variation of the climate change impacts, our analysis refines the conclusions published on the global impacts of climate change on European forests so far by Nabuurs *et al.* (2002) and Karjalainen *et al.* (2002). It also confirms the more recent hypothesis for a strong regional pattern in the 1990–2050 predictions for age-independent net ecosystem productivity, with larger increases in net ecosystem productivity for the boreal zone and a decline across Mediterranean forests (Milne and Van Oijen, 2005).

Pathogens and Risks

Several types of models were used to simulate the effect of the climate change scenario on pathogens and diseases: statistical biogeographical models based on distribution data from specific surveys, a specific epidemiological model (Marçais *et al.*, 2004) and the generic model CLIMEX (Sutherst *et al.*, 1999). Unsurprisingly, poleward extension of thermophilic pathogen and insect species and associated damage risk is predicted. However, the favourable effect of warming would be counterbalanced by the negative effect of decreased summer rainfall for some species. Due to the high dispersal potential of many fungi, the colonization of new regions becoming climatically favourable could put them into contact with naive host populations, i.e. with no co-evolution or co-adaptation history, with the same potentially dramatic consequences as those observed with introduced parasites (Harvell *et al.*, 2002). An example of such changes is provided by the pine processionary caterpillar (*Thaumetopoea pityocampa*) which has shown a recent latitudinal and altitudinal shift in Europe together with a switch on a new host, i.e. the first report on Douglas fir (Robinet *et al.*, 2007).

Fires

In Mediterranean and southern temperate forests, the duration of the annual period where fire risk is high will be extended by climate change (Pinol *et al.*, 1998). Together with the ongoing land abandonment and the increase in urban areas, and peri-urban forest areas where ignition frequency is highest, the risk of fire in southern, mostly unmanaged, forest ecosystems will increase, as already observed since the 1970s (Mouillot and Field, 2005). Under a changing climate the fire return interval might decrease from 72 to 62 years for Mediterranean forests and from 20 years to 16 years for shrublands (Mouillot *et al.*, 2002). In turn, the fire frequency curbs the extension of forests into southern Europe, as fire frequencies producing two successive fires too close together lead to domination by fast growing shrubs or resprouting species and can suppress the rest of the community. Indeed, at the landscape level, we observe nowadays a mixture of 28% of forest, 33% low maquis, 5% high maquis. Under changing climate, forest will only account for 12% whereas low maquis cover will increase to almost 45% and high maquis to 16% (Mouillot *et al.*, 2002).

Extreme Events

Extreme climate events, such as the windstorms in 1999 and 2002 and the 2003 heatwave in Europe, dramatically affect forest ecosystems, especially those where the management practice does not facilitate rapid damage repair. Although there are converging reports indicating an increase in the occurrence and severity of extreme climate events (Tebaldi *et al.*, 2006), their quantitative impacts and especially their long-term effects are not well understood or documented. Dendro-ecological surveys indicate that severe drought has initiated the dieback of broadleaf and coniferous trees and forest stands. Such long-term effects remain beyond the prediction capacity of current models (Becker *et al.*, 1988).

Managing Forests in an Uncertain Future

Where climate change effects are beneficial to forest functions, in northern temperate and boreal forests, our results suggest that optimizing forest management should aim at reducing the effects of limiting factors, for instance through fertilization. Conversely, where detrimental effects of the future climate are expected through increased water deficit, in southern temperate and Mediterranean forests, enhancing the ecosystem's resistance to drought and fire, species substitution, understorey control, site preparation and reductions in the maximal value of LAI could be appropriate strategies to adopt.

The complex interaction between climate and atmospheric composition calls for (1) an assessment of the entire environment rather than single factor response and (2) regional studies enabling us to account for local features of the forest environment and management. The forest function must also be considered.

Since climate change is provoking a continuous – but not monotonous – change in site productivity the management of a given forest must be revised dynamically during its lifetime. At the southern margin of geographical areas, management aiming at an optimal adaptation of forests should be considered, favouring, for example, multi-age and mixed forest stands, including pre-existing species and their southern variants and maximizing the intra-specific diversity.

In that risks will be more frequent and severe, forests may possibly be specialized and designed for a limited number of specific functions rather than managed in a multipurpose way. For instance, wood production may preferably rely on short rotation forests managed in an ecologically sustainable way such as compensating the nutrient export and satisfying water requirements by controlling the understorey vegetation and appropriate thinning. Other functions such as biodiversity, conservation, water and landscape management may be assigned to specific forest sites with alternative management approaches including longer rotation, multi-age and mixed stands which may not remain compatible with the optimal production of wood.

Finally, disease management in forest ecosystems has to rely on an anticipatory and preventive approach, based on risk analysis. Since simulated geographic ranges are only potential 'envelopes' in which parasites may establish, depending on their dispersal ability, the application of strict hygiene measures, based on the most probable dissemination pathways of organisms (in seeds, wood, plants), is necessary in order to delay the establishment of parasites in climatically favourable zones.

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Forest Responses to Global Change in North America: Interacting Forces Define a Research Agenda

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Introduction

The atmospheric concentrations of greenhouse gases (GHGs) are increasing and, in response, global climate is undoubtedly changing (IPCC, 2007). The establishment, growth and mortality of forest trees, and the productivity and health of forest ecosystems, depend greatly on climate. If the Earth was composed of uniform surface features, the nature and distribution of future changes in climate would be reliably and accurately predictable, and the forest responses only slightly less so. However, the globe is not uniform, instead having a heterogeneous surface of heat-absorbing oceans, variously light-reflecting mosaics covering the continents, circulation-blocking (and water-extracting) mountain ranges, highly reflective ice caps and so on. These features preclude the accurate prediction of GHG-induced climate change and hence, of forest responses to the coming changes. Uncertainty is enhanced by the fact that climate appears to be changing at such a rapid rate that long-lived trees will be unable to adapt within a single life cycle.

Yet, enough knowledge and theory does exist to provide initial understanding of the nature and distribution of the coming climate changes. For example, the Intergovernmental Panel on Climate Change (IPCC, 2007) tells us that climate is warming and will continue to do so by between 2 and 6°C a century, more over continents than over oceans, more at the poles than at the equator (Plate 8), more in winter than in summer, and more in night-time than in daytime. It tells us that the hydrological cycle is intensifying and will continue to do so, with increasing evaporation and evapotranspiration especially in mid-continent areas, increasing numbers of large storms rather than small ones, and greater frequency, length and intensity of drought conditions.

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We also know enough about tree and forest response to climate and climate change to predict their likely qualitative impacts. We have a great store of information on the daily, seasonal and annual temperature response functions of photosynthesis and respiration and on the responses to soil moisture which are needed to predict growth. We also have response functions for mortality and decomposition, responses to inadequate soil moisture for seedling germination and establishment; responses to heat, surface moisture and evaporation; of stand and ecosystem productivity responses to climate and climate variation.

We would claim to know enough about tree and forest response to predict accurately the outcomes of changing climate over the next few decades, in terms of species success, forest productivity and ecosystem carbon sequestration, over much of the earth. If it was only climate that was changing, we would be largely correct. But, the climate is not the only global environmental condition that is changing and affecting the forest responses to climate. Additional forces/factors will always accompany and interact with climate forcing, rendering meaningless any consideration of climate change effects alone. This chapter briefly discusses some of these interacting forces as they determine forest management options in temperate and boreal regions of North America, including insect and disease infestations, wildfire, air pollution and land use.

Direct Effects of Climate Change on North American Temperate and Boreal Forests

As predicted by general circulation models (GCMs) of the atmosphere, the increases of global surface temperature recorded so far have been greatest over the land masses of North America and over northern Europe and Asia (IPCC, 2007). This implies that the vast expanses of boreal and northern temperate forests of these regions are at particular risk of early climate change impacts. With current North American warming concentrated in the north and west (Plate 8), there is already evidence to support this expectation. Where permafrost has thawed beneath growing trees at high latitude, lowland black spruce (*Picea mariana*) are toppling over in extensive areas as soils undergo flooding and anaerobic conditions. In contrast, upland white spruce (*Picea glauca*) in the same regions are dying as warmth dries soils beyond the wilting point in these areas of low annual precipitation (Barber *et al*., 2000). These direct effects of climate change are being expressed now, and are expected to intensify and diversify in the near future (Corell *et al*., 2005).

Elsewhere, another suspected direct effect of climate change, increasing hurricane intensity in the Atlantic basin (Emanuel, 2005), may soon be confirmed with more definitive scientific research (Knapp *et al*., 2007; Kossin *et al*., 2007). Hurricane Hugo in 1979 and Hurricane Katrina in 2005 were both unusually intense storms which damaged or destroyed 1.5–2 million hectares (ha) of valuable southern pine forests in the USA. Predicted increases in hurricane intensity and their redistribution northward along the US Atlantic coast would be expected to increase this type of damage in future.

Despite these noteworthy examples of direct climate effects on forest growth and productivity, such effects cover little territory as yet. In fact, we suggest that direct effects of current and near-future climate changes on forest structure and function are of less current importance than the effects of climate change operating indirectly through other environmental stresses. The most prominent (and by no means only) examples of these indirect effects are discussed briefly below.

Indirect Effects of Climate Change on North American Temperate and Boreal Forests

Insect infestations

Infestations by bark beetles and defoliating insects are a natural component of forest ecosystems in North America, but recently infestations have been more intense than at any time in recorded history (Breshears *et al.*, 2005). On the Colorado Plateau and the central Rocky Mountains, mountain pine beetles (*Dendroctonus ponderosae*) have recently killed over 1 million ha of western yellow pine (*Pinus ponderosa*), and 1.5 million ha of piñon pine (*Pinus edulis, Pinus monosperma*), virtually emptying the piñon–juniper woodland of its piñon element in this region. This decline has been even more rapid than that which occurred in response to severe drought 50 years earlier (Allen and Breshears, 1998). Although the future piñon pine regeneration may not be eliminated, it will certainly be retarded by the shift to warmer and drier conditions.

The mountain pine beetles have been unusually destructive for several reasons. Their populations have been enhanced by a record-breaking drought from 2000 to 2004 (Kitzberger *et al.*, 2007) and by longer growing seasons, as predicted earlier by GCM simulations. While the drought facilitated growth of beetles and beetle populations, it reduced the ability of the pines to defend themselves by reducing the sap that would normally envelope beetles as they bored into trees. Hence, if this drought is a facet of the predicted intensification of droughts predicted by GCMs, it has indirectly impacted the pines by its enhancement of beetles (Fig. 19.1).

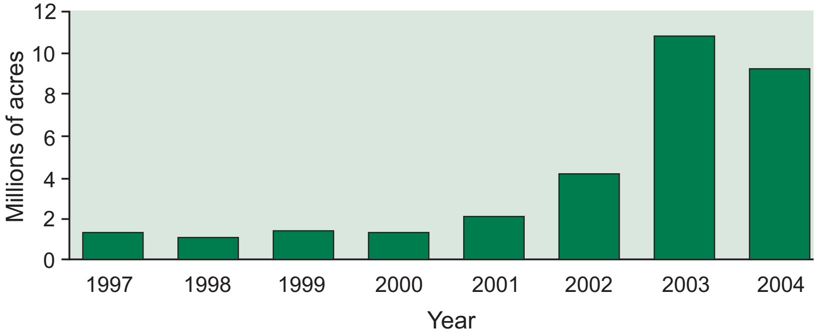

Fig. 19.1. Areas in millions of acres (2.47 acres = 1 hectare) of aerially detected bark beetle-caused tree mortality in the western USA before and during the drought of 2000–2004 (USDA Forest Service, 2005).

Further north, the mountain pine beetle has reached epidemic levels several times over the past century, but is currently at its worst ever recorded level in British Columbia. It is thought that as much as half of the pine stands in the central and southern interior could be dead by the summer of 2007 (British Columbia Government, 2007). Here, much of the blame for the beetle population density has been put on warming which has allowed the beetle to mature in one growing season rather than the normal 2-year maturity required by the cold winters there (Carroll *et al.*, 2004), effectively doubling populations.

Warmth, too, appears to be permitting beetles to invade northern pine populations previously inaccessible to them by virtue of too-short growing seasons. The mountain pine beetle, having reached the northern limit of lodgepole pine (*Pinus contorta*) in British Columbia and crossed the Canadian Rockies, is now entering a small area where lodgepole populations mix with the closely related jack pine (*Pinus banksiana*). Jack pine populations, previously beetle free, stretch the width of North America from Alaska southeasterly to the Atlantic Coast of Canada and the USA. There are many fewer winter thermal constraints on beetles once they begin migrating east in the jack pine populations and the beetles are predicted to spread rapidly throughout eastern North America (Logan *et al.*, 2003). In the meantime, southern pine beetle (*Dendroctonus frontalis*) is migrating northward from its natural range in loblolly pine (*Pinus taeda*) to threaten white pine (*Pinus strobus*) populations in New England and the Great Lakes region (Plate 9).

Wildfires

Wildfire too is a natural part of the landscape ecology, especially of western North America. Before European immigration, surface fires burned the woodlands and dry forests of this region every 5 to 20 years, eliminating seedlings and keeping fine and coarse fuels from attaining high densities, thereby reducing the frequency of stand-replacing crown fires. In more mesic, higher elevation forests, where fuels were much more dense, the fuels rarely dried out enough to permit fire, so any wildfire would be a stand-replacing type and return intervals there varied from 200 to 400 years (Agee, 1993).

In historic times, tree density in piñon–juniper woodlands and open yellow pine forests has increased greatly, as grazing of the past century eliminated fine fuels that carried the frequent seedling-destroying surface fires. Meanwhile, the fire suppression of the past 60 years, and logging strictures of the past 20 years, have permitted both increased growth of established trees and establishment of many other trees. This 'densification' of dry woodlands and forests has shifted the fire regime from dominance by surface fires to increasing frequency of stand-replacing crown fires. It has facilitated the growth of beetle populations as discussed above by providing increasing food sources at decreasing distances between trees.

Further up mountain slopes in the naturally dense conifer forests of western North America, increasing length of the growing season and warmer summers in the past 20 or 30 years have permitted normally damp fuels to dry, promoting an increased frequency of large, stand-replacing fires (Westerling *et al.*, 2006).

The result of longer, warmer summers since 1986 in the woodlands and forests of the USA, has been a six-fold increase in the area of forest burned compared to area burned from 1970 to 1986 (Running, 2006). A similar increase in wildfire activity has been measured in Canada from 1920 to 1999 (Gillette *et al.*, 2004). Indeed, according to the USA National Interagency Fire Center statistics (www.nifc.gov/stats/), the 2006 fire season in the USA involved some 4 million ha, more than any year in the past 65 fire seasons during which statistics have been kept. The role of a warming climate in promoting current increases of severe wildfire has thus, indirectly, reduced forest productivity on the burned-over lands and led to the release of large amounts of stored carbon. Consequent soil fertility losses and erosion following intense fires may require centuries to restore (Kashian *et al.*, 2006).

In addition to the climate–wildfire synergism described above, a wildfire–insect synergism is frequently important. Trees damaged but not killed by wildfire will attract large numbers of pathogenic insects from as much as 50 km away, with subsequent rapid increases in density of insect populations from chronic to acute levels. Once a high insect population density is achieved, attacks on adjacent healthy trees are usually successful, thereby spreading an epidemic. This synergy, of course, is intensified by the warming which dries forests and enhances insect population growth.

Air pollutants

The role of climate change in enhancing impacts of air pollutants is somewhat more ambiguous than its role in increasing impacts of insect infestations and wildfires. However, clearly, trees stressed by low-growing-season soil moisture or warm winter temperatures, will be more vulnerable to the negative effects of fumigation and deposition of acid rain, sulphur dioxide, nitrogen compounds and tropospheric ozone (Pan *et al.*, 2004), as is common in the forests of eastern Canada and the USA, and in certain areas of the southwestern USA. The theoretical growth advantages to trees of increasing atmospheric carbon dioxide (CO_2) concentrations disappear when the accompanying tropospheric ozone concentrations are considered as well (Karnosky, 2005). McLaughlin *et al.* (2007) determined that ambient ozone concentrations have already caused periodic reductions in mature tree growth of 30–50% from daily increases in water use and consequent decreases in soil moisture availability in the southeastern USA. These results suggest that warming-induced water stresses to trees will be amplified by tropospheric ozone, and will also reduce at least late-season stream flows from forests.

Land use and land management

In addition to the ubiquity and synergy of the foregoing stresses to tree and forest growth, land use and land management practices, particularly in the western USA, will continue to exacerbate these stresses. Foremost concern is directed at the expansion of the wildland–urban interface. The ability of people to live distant from the workplace and to commute from remote areas is part of this recent phenomenon. In addition, the construction of second homes and other vacation structures has increased greatly. Now, low-density rural residential land use covers 25% of the land in the western USA. This permanent presence of recreational infrastructure has greatly complicated forest management by requiring the focus of fire suppression resources to be spent on protecting structures, rather than on dealing with each wildfire as a whole. During the past 10 years, fire suppression costs to the US Forest Service have risen from 20% of the discretionary budget to a projected 50% in 2008, yet losses of life and property have continued to increase.

Recreation in the USA and Canada increasingly involves use of off-road vehicles that destroy tree seedlings and delicate plant communities when used in the absence of snow cover, and spread seeds of exotic invasive plants far from roads where they can be detected and controlled. If off-road vehicle drivers are careless with fire, the frequency of fires will increase at locations far from established roads, in difficult terrain which is largely inaccessible to firefighters. Neither the spread of recreational homes, nor the increase of recreational vehicles is likely to abate in the next decades. Rather, it is likely to continue to impact land management actions that might be taken in response to changing climate and the other disturbances discussed above.

A Research Agenda for Managing North American Temperate and Boreal Forests of the Future

The management of forests under chronic climate change during the next few decades will be aimed at reducing the impacts of climate variations and the ubiquitous synergistic stresses of natural and anthropogenic disturbances, and at the same time enhancing carbon sequestration to reduce GHG concentrations. Direct effects of climate change, as exemplified by black and white spruce declines in boreal regions, and possibly by forest destruction from intense hurricanes inland from coastal Atlantic and Caribbean waters, are now visible but are hardly widespread.

Certainly, as GHG concentrations continue to rise, direct effects of climate changes will become increasingly important in determining forest health. Processes not even measured on landscapes now will become increasingly critical by the end of this century. The most obvious example is the gradually deepening ‘climate obsolescence’ of current tree species distributions. This gradually increasing disconnection between tree populations and their preferred climate is worsened by their poor ability to migrate and the need for decades and centuries for effective establishment. Indeed, considerable uncertainty surrounds the ability of some species to complete their life cycles in areas which currently have suitable climate, before the climate changes and makes them ‘obsolete’ again. The eventual result of climate changing about 10 times as rapidly as tree population shifts (Solomon, 1997) is likely to be a greatly reduced carrying capacity of trees and biomass, and a gradual reduction in tree species flora, with domination by weedy species (Solomon and Leemans, 1990) perhaps detectable by the end of this century.

In contrast, the next several decades of management problems are likely to be dominated by indirect effects of climate variance, operating through increasing disturbances by insects and wildfires, and increasing effects of air pollutants and land-use practices as the foregoing illustrates. The problems caused by the certainty that climate and disturbance regimes will never be the same as they were in the past century, will be exacerbated by the uncertainty of what those regimes will comprise at any given location where management must be applied in the next few decades. This conundrum will be compounded by another: the need to increase carbon sequestration in forests, towards which we already see the decision makers leaning, versus the need to reduce forest densities if we are to provide forest resilience to increasing synergistic stresses, and maintain the various other ecosystem services which are provided by forests. It is these competing needs and uncertainties that the forest management research agenda must address.

Many techniques and approaches are available for forest management under uncertainty (Millar, 2007). We will focus on two that hold the most direct promise in the near future but recognize that no single or few actions can be expected to solve all the management problems. Perhaps the most obvious action is the reduction of forest density and the resulting increase in the amount of soil moisture and nutrients available to the remaining trees. It seems likely that forest dieback in the later 20th century in western Europe and the northeastern USA reflected a 'natural thinning' in response to increased stresses. Since the demise of many large trees, those remaining are much healthier despite only minor changes in atmospheric pollutants, water availability and acid rains. Similarly, reducing forest density to reduce competition for resources should enhance resistance of the remaining trees to the coming environmental stresses. The coincidental benefits of thinning, in reducing proximity of trees to be attacked by insects, and reducing fuels to carry wildfire, are obvious. Use of the removals and residuals in additional wood products and biofuels also permits mitigation of atmospheric CO_2 while facilitating the sequestration of still more carbon. However, the variety of ways to reduce forest density produce uncertainty regarding which of those to employ for optimum stand resilience and maximized carbon sequestration in any specific location. Clearly new field and laboratory research on the topic is urgently needed.

A second important approach to increasing forest resilience is to increase the diversity of trees available to grow. Afforesting and reforesting the areas harvested or undergoing major disturbances can utilize mixes of faster-maturing species and seed provenances that are better adapted to moisture stress and reduced evapotranspiration, as well as those capable of thriving under warmer winters and earlier springs. We do not need to know which of several potential climate regimes will dominate in the next 50 years in a given locale, to select a mix of species from which some elements will be capable of growing under that climate uncertainty. This approach implies a considerable increase in research utilizing transplant gardens, glasshouses and laboratories, and involving genetic selection of appropriate species and provenances.

The implementation of resilience by reducing forest density and enhancing the genetic base are but two examples of the kinds of research which must be undertaken. In any case, the expectation is that synergistic and inseparable stresses from changing climate and disturbance regimes, both natural and anthropogenic, must guide the research agenda of the next few decades. Current information as presented here suggests that the most vulnerable tree populations and forest ecosystems are undergoing losses, and that the currently direct impacts of climate change on forests will gradually increase in intensity and geographical extent.

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V

National and International Frameworks: Current and Future Policy

At UNFF6 in 2006 the UN Forum on Forests agreed four new global objectives on forests, as follows (www.un.org/esa/forests)

1. Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation.
2. Enhance forest-based economic, social and environmental benefits, including improving the livelihoods of forest dependent people.
3. 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.
4. Reverse the decline in official development assistance for sustainable forest management and mobilize significantly increased new and additional financial resources from all sources for the implementation of sustainable management.

In this section we consider monitoring systems and the national and international pressures which have led to the establishment of the UNFF, its objectives and the framework for their delivery.

20

National Forest Monitoring Systems: Purposes, Options and Status

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Introduction

Forests and forestry are subject to a variety of political processes and high-level decision making that affect everyone's habitat and/or livelihood. But do we actually know what we need to know for dealing soundly with forests and forestry? Are there monitoring processes in place to ensure that sufficient knowledge about forests and forestry is generated to reduce uncertainties and support wise decisions?

Over the past decades, at least 10 legal international instruments have been established that address specific aspects of forest resources, their management and uses (Ruis, 2001). Efforts to agree on an overall forest convention, on the other hand, failed at the United Nations Conference on Environment and Development (UNCED) in 1992. Although alternative explanations of this failure exist (Davenport, 2005), it is commonly acknowledged that the main argument against a forest convention was – and remains – the protection of national sovereignty. Many countries wanted to retain governance over national forest resources and not surrender decision making to a binding international agreement.

The UNCED negotiations thereby reinforced the national-level nature of forest policy and legislation. Over the following 14 years, the international dialogue has not closed in on any international and legally binding arrangement on forests (Persson, 2005). A starting point for this chapter is, consequently, that forest policy and legislation are inherently national-level processes and, further, that these processes depend on some form of national forest monitoring systems that meet defined requirements for the necessary decision making.

At the same time, the numerous forest-related international agreements that have been successfully established require parties (countries) to verify and substantiate their compliance through specified reporting arrangements of the

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Collaborative Partnerships on Forests (CPF, 2006). One key agreement relating to forests and forestry is the United Nations Framework Convention on Climate Change (UNFCCC) where a current debate concerns potential avoidance of carbon emissions from deforestation and from forest degradation. While interpretation and application of these concepts are to be negotiated, it is clear that national forest monitoring systems must be in place to follow and document the extent to which parties have adhered to the agreed intentions.

The question examined in this chapter is whether current national forest monitoring systems, or national forest inventories, respond to requirements from national policy decisions as well as international reporting requirements. National forest monitoring systems are defined here as processes that support strategic decision making by:

- systematically and repeatedly measuring and observing forest resources, their management, uses and users;
- periodically delivering valid, representative and relevant information on status and trends for the country as a whole.

Monitoring of operational forest management, including of legal compliance, early warning systems (for example, forest fires), of value-adding processing beyond the forest gate and of forest products are outside the scope of this chapter.

The chapter determines the purposes of national forest monitoring. It evaluates technical options and approaches for monitoring systems against these aims. Finally, the situation of national forest monitoring is reviewed with special reference to the current discussion on avoiding carbon emissions from deforestation and from forest degradation within the UNFCCC.

Purposes of National Forest Monitoring

The purposes of national forest monitoring can be defined by objectives as expressed by relevant policy processes, under the assumption that such objectives also, implicitly, express a demand for systematic and quality controlled information. Examining forest policy documents, including national communications to the United Nations Forum on Forests (CPF, 2006), national forest programme updates (FAO, 2006a), regional reviews (e.g. FAO, 1998) and global overviews (e.g. FAO, 2005), makes clear that forest policies are concerned with sociocultural and economic as well as environmental dimensions (Table 20.1). Further, it is often emphasized that the forest sector interacts with several other sectors, e.g. agriculture, energy, tourism and transport.

The broad set of forest policy objectives at national level resonates well with statements in the international dialogue on forests. Sustainable forest management, an umbrella concept for forestry ambitions, has been defined by seven themes (FAO, 2006b) which also contribute to overall sustainable development aspirations. The framework of sustainable forest management has been used to define information requirements for the Global Forest Resources Assessment process, in which countries report based on their national information sources (FAO, 2006c).

Table 20.1. Issues frequently mentioned in recent expressions of forest policy objectives (sources: CPF, 2006; FAO, 1998, 2005, 2006a).

Dimension	Issues
Sociocultural	● Rural livelihoods ● Indigenous people's rights ● Rights of access ● Tenure and land ownership
Economic	● Poverty ● Food security ● Wood productivity and supply ● Valuation of forest products and services ● Equity ● Trade ● Energy
Environmental	● Biological diversity ● Soil and water protection ● Climate change ● Desertification ● Air pollution ● Invasive species ● Wildfire ● Pests

Therefore, national forest monitoring systems need to be designed to deliver cost-effective and quality controlled information across the issues listed in Table 20.1. These systems must include a wide range of variables addressing biophysical as well as sociocultural and economic issues. In response to these requirements, the scope of the national forest inventory concept has recently been expanded from traditional measurements of trees and other biological features to include interviews with local forest managers and stakeholders (Kleinn *et al*., 2005; FAO, 2006d).

Other emerging foci of forest monitoring relate to climate change. On the one hand, the health of forests under potentially changing climate needs to be monitored for informed decisions and guidelines on adaptation of forest management practices. On the other hand, and as stated above, the mitigation of climate change through forest management by storing carbon in the forest ecosystem may become an economic and financial tool for forestry. Monitoring of carbon storage in the forest is closely related to variables covered by conventional national forest inventories, such as growing stock, growth and yield and forest area.

Options for National Forest Monitoring

This overview of technical options for national forest monitoring covers the methods for data collection and the approaches to the national monitoring task.

Data collection methods

The wide range of social, economic and environmental issues to be addressed imply a similarly wide variety of variables to be observed. Cost-effective methods for data collection have been a major focus in forest monitoring research (e.g. Ranneby *et al*., 1987; Gillis *et al*., 2005; Kleinn *et al*., 2005). Balancing requirements on accuracy and precision for the monitored variables with the cost of obtaining data from the field poses a classical problem of forest inventory. Cost may be prohibitive for systematic observations of some variables, e.g. soil carbon content. For others, key shortcuts include (1) applying statistical sampling – out of a wide variety of existing methods, (2) using subjective observations rather than more costly measurements, and (3) remote sensing to reduce the need for fieldwork. Further, some variables are not directly observable as they reflect human perceptions and values, so data have to be collected through interviews with local stakeholders. Table 20.2 summarizes basic methods of data collection that are used in national forest monitoring systems. It is well established that a combination of these methods is required to monitor the range of identified forest and forestry issues at the national level.

Approaches

National forest monitoring systems, as defined above, should systematically and repeatedly measure and observe forest resources, their management, uses and users. However, many countries have not established such systems, or have systems that can be only partially characterized as a national forest monitoring system (FAO, 2006c).

The design and implementation of national monitoring of forests can be seen as an investment in information that pays off through increased future benefits to society accruing from forest resources. However, these increased benefits, and thereby the return of the investment, are often not well known and cannot be

Table 20.2. Basic data collection methods for national forest monitoring systems (source: builds on Holmgren and Thuresson, 1998; Andersson, 2006; Kleinn, 2006).

Data collection method	Feasible variables	Pros	Cons
Field measurements	Biophysical properties	Precise	High cost Limited to measurable variables
Field observations	Biophysical properties Land use	Wide range of variables possible	Relies on field staff judgements
Remote sensing	Area measures for some variables	Cost-effective (?) Supports fieldwork performance	Low accuracy Few relevant parameters possible
Interviews	Resource uses, users, values, tenure, conflicts	Only way to capture local socioeconomic information	Demanding methodology Difficult to control bias

easily generalized. The monitoring approach and ambition chosen by a country will depend on many internal factors that are not analysed here.

Instead, a generic range of available approaches, currently in use, has been developed for this chapter (Table 20.3), based on country reports to the Global Forest Resources Assessment 2005. While no comprehensive evaluations of these approaches are made here, Table 20.3 indicates a measure of quality and reliability in the derived information, with the highest quality and reliability at the top and the lowest at the bottom.

Table 20.3. Optional approaches to generate national forest information, with examples from sources for the Global Forest Resources Assessment 2005.

Approach	Typical properties	Pros	Cons	Examples (FAO, 2006c, 2006d)
National forest inventory				
Traditional national forest inventory	Many (>10 000) systematically sampled field plots Focus on biophysical variables	High precision and accuracy	High cost Long implementation Normally limited to biophysical variables	Sweden Finland
FAO-supported national forest assessment	Few (150–500) systematically sampled tracts Measurements, observations and interviews	High accuracy Covers wide range of variables Medium cost Short implementation	Low precision for rare events Trends not yet available	Guatemala Philippines
Other approaches				
Compilations of forest management plans	Assembly of information obtained from obligatory management planning activities	Strong link to policy implementation	Scope normally limited to forest operations planning May not cover all forests	Russia
Remote sensing based	Trends in land cover and land use from image classifications	Full cover information Comparable time series	Limited scope of variables	Brazil
Independent reports over time	Surveys which are not fully compatible (often based on remote sensing) are compared on the basis of assumptions	Pragmatic (only) option in many countries	Relies on assumptions for comparisons	Ecuador
Case studies and/or models	Conditions at selected sites are extrapolated	In-depth information for selected sites	Not representative for entire country	Zambia
Expert estimates	Qualified guesses where only scant information exists	Quick and inexpensive	Unknown information quality	Sudan

Status of National Forest Monitoring

Two basic forest parameters were selected to illustrate the current status of national forest monitoring. These are highly relevant to the current discussions on deforestation and forest degradation in the climate change context:

- *Forest area change*, i.e. the aggregated area change (net change) resulting from deforestation, afforestation and natural expansion of forests (FAO, 2006c, p. 14).
- *Forest carbon stock changes* (FAO, 2006c, p. 31).

For each parameter, the monitoring approach was classified according to the categories in Table 20.3 for all countries and areas that reported to the Global Forest Resources Assessment 2005 (FRA, 2005). It is assumed that essentially all available and relevant information has been used for the FRA 2005 reporting from countries (FAO, 2006c). To make the results relevant in the climate change context, countries were grouped into those that are listed in the Annex I of the Kyoto Protocol, and those that are not. Broadly speaking this also divides the world into developed and developing countries.

A total of 229 countries and areas reported to FRA 2005. Of these, 41 (mainly dependent territories) are not parties to the UNFCCC and are excluded in the presentations below; they represent only 0.5% of the global forest area. Altogether 148 countries of those reporting to FRA 2005 have signed the climate change convention, but are not 'Annex I' parties of the Kyoto Protocol and are therefore referred to as 'non-Annex I countries'. Forty countries have signed both the conventions and are listed in Annex I of the Kyoto Protocol and are referred to as 'Annex I countries'.

The world's forest area is nearly evenly distributed between Annex I countries (1.8 billion ha) and non-Annex I countries (2.1 billion ha). However, almost all current net loss of forest area occurs in non-Annex I, i.e. developing, countries.

Figure 20.1 illustrates how the world's countries monitor their forests with respect to the two selected parameters. Annex I countries have an even distribution of approaches across the monitoring categories, while the majority of non-Annex I countries (85% of countries in the case of forest area and 92% of countries in the case of carbon stock) rely on independent assessments, models or expert estimates rather than systematic inventories. Plate 10 illustrates examples of countries that have recently adopted systematic monitoring, but where trend estimates based on the systematic sample cannot be determined until a second inventory round is completed. For non-Annex I countries, the monitoring of carbon stock is dominated by lack of data and expert estimates.

Table 20.4 provides the same breakdown, but shows the proportion of global forest area subject to the different monitoring approaches. The distribution is similar to that shown in Fig. 20.1, implying that the lack of systematic monitoring approaches is spread among larger as well as smaller countries.

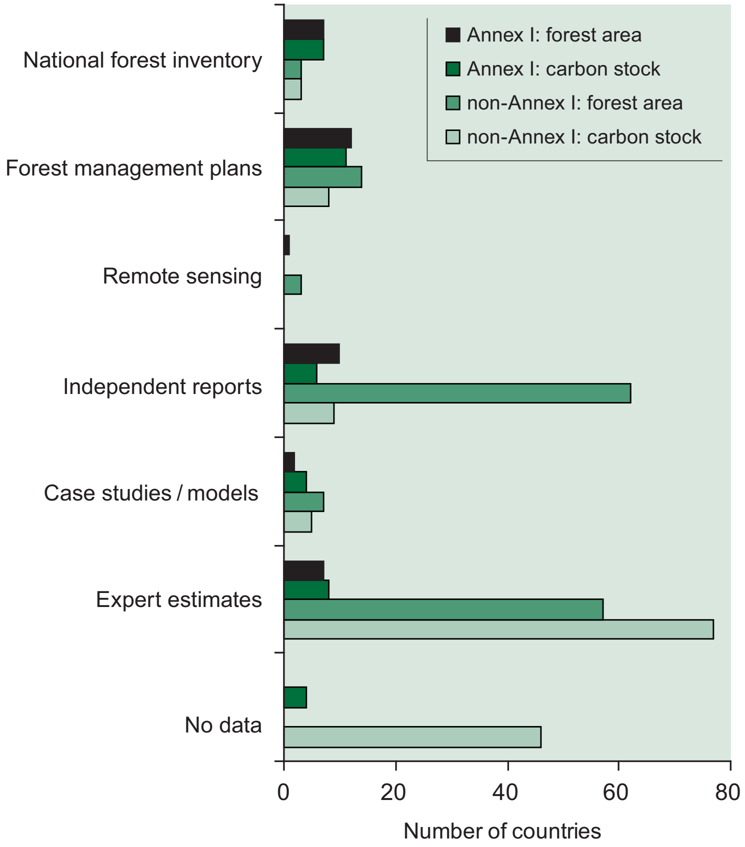

Fig. 20.1. Forest monitoring approaches as applied by countries to estimate forest area change and forest carbon stock change (based on FAO, 2006c). Annex I indicates countries that are listed in Annex I of the Kyoto Protocol, non-Annex I indicates countries that are not listed.

Discussion and Conclusions

The results show that forests are not systematically monitored in the majority of countries and especially not in non-Annex I countries on which current discussions on deforestation and forest degradation in the UNFCCC context focus. This means that it is not possible to determine accuracy and precision of reported information for most countries. The quality problem of relying on independent assessments or expert estimates is well illustrated by Global Forest Resources Assessment 2000 findings, where the forest area changes reported by African countries were overestimated by more than a factor of two, compared with a systematic remote sensing survey (FAO, 2001). Conclusively, current monitoring of forests seems insufficiently accurate or precise for an international protocol that would administer finances based on monitoring results of forest area or forest carbon storage.

Table 20.4. Global forest area subject to monitoring approaches for the two parameters: forest area change (ha yr$^{-1)}$ and forest carbon stock change (t ha^{-1} yr^{-1}).

	Forest area subject to monitoring approach (million ha)							
	Forest area change				Forest carbon stock trend			
Monitoring approach	Non-Annex I	Annex I	Total	% of total calculated	Non-Annex I	Annex I	Total	% of total calculated
National forest inventory	216	370	586	14.9	216	370	586	14.9
Forest management plans	49	859	908	23.1	16	853	869	22.1
Maps	129	164	292	7.4	0	0	0	0.0
Independent reports	883	85	968	24.6	744	65	810	20.6
Case studies/models	622	11	633	16.1	30	30	60	1.5
Expert estimates	218	326	544	13.8	852	15	867	22.0
No data	0	0	0	0.0	258	482	741	18.8
Total	2118	1815	3932	100	2118	1815	3932	100

In addition, at least one of the two parameters examined above, forest area, is very basic and usually the first to be considered in a national forest monitoring system. While carbon stock is a more novel forest parameter of interest, according to the applicable guidelines (IPCC, 2003) it is simply a deterministic function of forest growing stock, another basic component of national forest inventories. Conclusively, there appear to be considerable opportunities for synergies between general requirements of national forest monitoring and the specific requirements of the climate change related arrangements.

Underlying causes

The call for better forest information for policy making is not new (e.g. Pinchot, 1923). What may be surprising is that so astonishingly little has been done over the past decades to ensure the supply of solid forestry information – despite the considerable attention and focus on forestry in a large number of international fora, as described above, and despite the considerable international development assistance provided to the forest sector (Holmgren and Persson, 2002).

Before marching ahead and implementing national forest monitoring systems, however, there may be reasons to investigate further why investments in such systems have not been sufficient in the past. As proposals for future studies, the following hypotheses are suggested:

- The politically driven demand for national forest and forestry information for policy-related decision making is smaller than the international dialogue on forests suggests. In competition with other government activities, the monitoring of forests and forestry to determine actions that pay off in a relatively distant future are not prioritized.

- The awareness, knowledge, experience, engagement, opportunity or influence of forestry professionals and their institutions are insufficient to establish commitments to long-term national forest monitoring efforts.
- Methodologies to meet relatively new, and constantly changing, demands for information take time to develop, share and implement and may be outdated when finally delivered. Method developments may also have been biased by an overbelief in the technical performance of remote sensing methods, which has slowed down the development of field-based monitoring.

Opportunities and Challenges

To end this chapter with a positive outlook, there is reason to believe that awareness and prioritization of national forest monitoring systems are on the rise; examples include Brazil and Russia who have recently made decisions to invest in national forest inventories. Several developing countries work at institutional as well as field level to improve national forest monitoring in collaboration with the Food and Agriculture Organization (FAO, 2006d).

Integrated approaches to national forest monitoring promise to be effective. One reason is that many variables overlap between the policy issues to be addressed. As mentioned above, key variables for carbon monitoring are also key variables for monitoring productive functions of forests as well as biological diversity. Further, given that field sampling and inventory is the preferred approach to national forest monitoring, the benefits of the considerable effort of reaching field sample locations should be maximized by collecting many parameters while there. In conclusion, there appear to be strong arguments to incorporate currently debated requirements for forest carbon monitoring in the established general approach to national forest monitoring, thereby potentially improving the financial base for monitoring as well as enhancing future benefits of overall forest management.

There are further opportunities for integrating national monitoring approaches, extending beyond forests and forestry to other land uses and related natural environments. In many countries, forest resources extend over all land, including woodlands and trees outside of forests. As these resources are important to forest-sector policies, national forest monitoring often extends to all land. Sampling all land provides opportunities for development and implementation of inter-sectoral national land-use monitoring as the additional cost to collect agriculture variables, for example, may be small. Such inter-sectoral approaches may (1) help enhance institutional collaboration in countries, (2) make better use of scarce inventory resources and (3) provide improved possibilities for inter-sectoral land use analyses and policy formulation (FAO, 2006d).

Providing the relevant information to the relevant people at the relevant point in time at relevant cost are fundamental challenges for national forest monitoring systems. Competition for public finances and the fact that returns on the monitoring investment accrue in a relatively distant future add to the difficulties. Yet, our livelihoods depend heavily on the future of forest resources and the environment, calling for wise decisions on all levels, which suggests that the market for monitoring and quality information could expand.

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21 Conservation of Biodiversity in Boreal Forests: the Russian Experience

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Introduction

The global value of forests is universally accepted. They make a positive contribution at numerous levels, including the atmosphere, hydrosphere, soil, biodiversity, and in a social context. Forests are a source of life for many forest dwellers and also for many people who live outside forests because they produce oxygen, act as a source of water to the atmosphere and maintain water quality. Forests represent a huge gene pool and refuge for biodiversity. When we talk about forests and trees, we should also talk about soil and water, permafrost and wetlands biodiversity, as well as the atmosphere and their contribution to social and health objectives.

The biodiversity associated with forests is often cited as being of more importance than that of other ecosystems. Tropical, temperate and boreal forests provide a wide spectrum of habitats for plants, animals and microorganisms. Forest biodiversity provides humans with resources and ecosystem services, ranging from timber and non-wood forest products to mitigating the impacts of climate change; it also constitutes a significant social and cultural value for indigenous peoples and local populations. Forests themselves provide employment for hundreds of millions of people around the world.

The recent Forest Resources Assessment (FRA) published by UN FAO indicated that forests cover 30% of the world's total land area, and that the total forest area continues to decrease, but at a declining rate. Deforestation, primarily through land-use change is still at a very high level, comprising some 13 million hectares (ha) per year. Primary forests represent the richest source of biodiversity, accounting for 36.4% of forest area, but their rate of loss or modification is alarmingly high at 6 million ha per year (FAO, 2006).

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Endangered Tree Species: Causes and Extent

A new assessment of biodiversity loss in tree genera was recently published by the FAO. Eighty-eight countries contributed to the Global FRA-2005, with the most common tree species reported being pine, oak, spruce, true fir and birch, comprising between 3.5% and more than 10% of tree genera for individual countries. Twenty-five tree genera represent 64% of all taxa reported. The FAO data also identify the range in the number of tree species native to individual countries, which varies from three in Iceland to 7780 in Brazil. Around 11% of the world's forests are designated for the conservation of biological diversity (FAO, 2006).

The richest forest biodiversity is in the humid tropics, specifically in rainforests. For example, a 10 ha plot of rainforest in Borneo may contain more than 700 species of trees – equivalent to the total tree diversity of North America – while a single rainforest reserve in Peru is home to more species of birds than are found in the entire USA (Rainforest Facts, 2006).

A recent breakthrough in mapping biodiversity is the report *Towards a Global Tree Conservation Atlas* prepared by Flora and Fauna International with involvement from a range of UN bodies and many other organizations (Newton *et al*., 2003). The report comprises a compilation of conservation summaries for the 7388 tree species broken down by the International Union for the Conservation of Nature and Natural Resources (IUCN) threat categories, as defined in 1994 (see Table 21.1).

Thus, out of more than 10 000 tree species reviewed, more than 10% are extinct or critically endangered and 85% (8753 species) are considered as

Table 21.1. Breakdown of threatened and endangered tree species by IUCN 1994 threat category.

1994 IUCN threat category	Number of species
Extinct	**77**
Extinct in the wild	18
Critically endangered	**976**
Endangered	1 319
Vulnerable	3 609
Lower risk: near threatened	752
Lower risk: conservation dependent	262
Data deficient	375
Subtotal	**7 388**
Lower risk: least concern	1 971
Not evaluated	732
Total number of species reviewed	**10 091**
Globally threatened Australian tree species	141
Globally threatened Japanese tree species	202
Additional globally threatened species: old IUCN threat categories	1 022
Total number of globally threatened tree species	**8 753**

threatened. The reasons for the decline and rarity of these threatened species vary. Felling represents the principal threat to 28% of those classed as threatened or endangered, with agriculture (20%) and bad management practice (5%) as other significant factors (UNEP, 2006).

It is clear that logging is one of the most pervasive threats to forest biodiversity in countries where the practice is commonplace (Brazil, Canada, Malaysia, Indonesia, the USA and Russia), while wildfires are also important, particularly in countries with vast forest territories and larger volumes of logging. In contrast, in Asia and Africa, land-use change (agriculture and expansion of settlements) as well as grazing and burning for agricultural purposes is often the principal threat.

International Initiatives to Halt Biodiversity Loss

Data on threatened tree species provides a general overview of global biodiversity issues on which to base responses to prevent further decline, and a number of measures have been undertaken. These methods, mechanisms and agreements include the UN Convention on Biological Diversity Conservation, the UN Convention on Deforestation and the Forest Principles.

In May 1992, the European Union adopted legislation designed to protect the most seriously threatened habitats and species across Europe, and the Natura 2000 network of protected sites was established. The EU-wide network now covers some 18% of the territory of the EU-15 and is being extended to the accession states and to the marine environment (Natura, 2000).

At the European Heads of State summit in 2001 it was agreed to halt biodiversity loss in the EU by 2010. This action was in response to an assessment that identified that between 30% and 50% of species present in the EU are threatened with extinction (42% of mammals, 43% of birds, 45% of butterflies, 30% of amphibians, 45% of reptiles and 52% of freshwater fish). In May 2006, the European Commission presented a new action plan on biodiversity that has four major foci: biodiversity in the EU; the EU and global biodiversity; biodiversity and climate change; and strengthening the European Research Area knowledge-base. This action plan launched a wide public debate that will contribute to developing a long-term vision on halting biodiversity loss (EU, 2006).

The TRAFFIC (www.trafic.org) process focuses on halting the illegal trade of rare and endangered species, and Millennium Goal number 7, in which nature conservation is an essential part, deals with environmental sustainability. Initiatives to achieve the biodiversity-related elements of the goal include Countdown-2010, which was launched by the IUCN Regional Office for Europe at the third IUCN World Conservation Congress in Bangkok, Thailand in 2004 (IUCN, 2004). It requires that all European governments and members of civil society, at every level, take the necessary actions to halt the loss of biodiversity by 2010. In May 2004, the scientific community initiated a barcoding of biodiversity; during the past 2–3 years more than 100 organizations from over 40 countries have joined the Consortium for the Barcode of Life (CBOL, 2005).

The initiatives on biodiversity reached business and financial institutions. For example, in April 2006, International Finance Corporation presented its Performance

Standards on Social and Environmental Sustainability. Performance Standard 6 on Biodiversity Conservation and Sustainable Natural Resource Management aims to protect and conserve biodiversity and to promote the sustainable management and use of natural resources through the adoption of practices that integrate conservation needs and development priorities (IFC, 2006).

However, the recent Second Global Biodiversity Outlook confirms that biodiversity is still being lost at all levels, and that

> Biodiversity loss is rapid and ongoing. Over the last 50 years, humans have changed ecosystems faster and more extensively than in any comparable period of time in human history. Tropical forests, many wetlands and other natural habitats are shrinking in size. Species are going extinct at rates 1000 times the background rates typical of Earth's past. The direct causes of biodiversity loss – habitat change, overexploitation, the introduction of invasive alien species, nutrient loading and climate change – show no sign of abating. As biodiversity loss proceeds, our knowledge of its importance is growing. (CBD, 2006b).

Russian Forests in the Global Environment

One of the most important features of the Russian natural environment is its forests which cover 45% of the land mass. Russia has the greatest expanse of intact boreal forest in the world. Although productivity is only a quarter of that of tropical forests in the Amazonian basin, Russian forests remove approximately 110 million tonnes of carbon (tC) from the atmosphere, annually. The total carbon stock of Russian forests has been estimated as 36–48 billion tonnes (Teplyakov, 2001). Furthermore, Russia is the only country with a significant timber industry in which the forest area is still increasing and, by virtue of this, it is an area of global significance to nature conservation and a 'donor' to many national ecosystems. Russia is also a source of biodiversity for neighbouring countries. More than 30 million ha of forests are IUCN category I and II protected areas and, overall, the area of protected forests is about 10% of total forest area. In its territory, 10% of all invertebrate species, 8% of insects, 14.5% of fish, 8% of birds, 8% of mammals and 1% of amphibians have been recorded.

In the context of forests and climate change, the Russian near-tundra forests are worthy of mention. They are 50 to 150 km in width and protect much of northern Eurasia from the cold air masses of the Arctic Ocean. These forests were excluded from timber harvesting and assigned a special designation in 1956. Biodiversity here is not as rich as at lower latitudes, but the area is now a vast protected reserve for migratory birds, animals including reindeer and polar vegetation. Research projects have not assessed the consequences of deforestation in the region for biodiversity or climate change.

Climate Change and Forest Biodiversity

The influence of the Russian landmass on the global environment, including its contribution to the hydrological cycle, is highly significant as a result of the vast expanse of wetlands, rivers and permafrost. Permafrost and other long-frozen lands represent a potential source of unknown diseases, methane emissions and other hazards due to global warming.

A range of different approaches, including tree ring analysis, pollen analysis and the modelling of carbon balance, have indicated current trends in Russia and these trends were highlighted at a seminal international conference in 2006: *Climate changes and their impact on boreal and temperate forests* (Ural State Forest Engineering University, 2006). The reported trends included a northward shift in the polar tree line in Siberian, Sayan and Ural mountain forests over the past 50 years, although in other regions such as the Yamal Peninsula, a similar shift is not evident. The data agree with studies in other countries which indicate that 'global warming is causing shifts in species spatial distributions that average 6.1 km per decade towards the poles.... Spring is also, on average, arriving 2.3 days earlier per decade in temperate latitudes, with the most extreme effects of global warming apparent in boreal and polar ecosystems' (CBD, 2006a).

The flora and fauna of Russia are also being affected by changes in seasonal precipitation patterns, shifts in seasonality and an increase in mean annual temperature in some regions. Furthermore, in the absence of severe winter cold in recent years, there has been an increase in the severity and extent of outbreaks of bark beetles and other insect pests. For example, the Siberian moth outbreak in 1993–1996 completely destroyed more than 1 million ha of taiga forests and, in 2001–2003, defoliation occurred over an area of more than 10 million ha. Similar infestations have also been observed in the USA (east coast) and Canada (British Columbia). There are concerns over further dieback of spruce forests in the boreal zone of Russia due to:

- an increase in the severity of bark beetle outbreaks because of a general deterioration in the health of forest trees;
- deterioration of the hydrological regime;
- evidence of a change in the virulence of *Fomitopsis annosa* and *Armillaria mellea*.

The causes of biodiversity loss in Russia are similar to those the world over. For example, forest fires destroy 1–2 million ha of forests annually with much larger areas burned in extreme years such as 2003, when more than 23 million ha were lost. The rate of deforestation has declined over the past 15 years from 1.5–2 million ha to less than 1 million ha. This has primarily been as a result of a decrease in timber harvesting. The annual rate of forest regeneration is close to 1.1 million ha, with the net result that the forest area in Russia is now increasing, while the area subject to severe pest outbreaks has declined over the past 3 years from more than 8 to about 3 million ha (Russian Forests, 2005).

There is no governmental body responsible for biodiversity conservation in Russia, although there are 100 nature reserves and 35 national parks covering more than 30 million ha. Poor management, a lack of effective legislation and illegal activities in forests hinder the development of a sustainable forest sector in Russia. Improvements are required to the administration of the sector alongside legal reform in the Russian Federation to ensure that sustainable forest management is practised and that the contribution of the sector to nature conservation is optimized.

Forest Legislation and Governance

Administrative reform and changes in the forest sector have led to a decision to develop a new Forest Code. In 2000, the abolition of the Federal Forest Service and the creation of the Russian Ministry of Natural Resources initiated the development of the new Forest Code, a Water Code and a reassessment of environmental legislation including the creation of an Act on Protected Areas.

In November 2006 a new version of the Forest Code of the Russian Federation passed its third hearing in the Russian State Duma. The new Forest Code includes many new initiatives. For example, Article 1: Key Principles of Forest Legislation states that:

> The following principles shall underlie forest legislation and other enactments governing forest relations:
>
> **1.** Sustainable forest management, biological diversity conservation in forests and enhancement of their potential.
> **2.** Maintenance of habitat-forming, water-conservation, protection, sanitation, recreation and other beneficial functions of forests, to ensure that each person can exercise the right for a healthy environment.
> **3.** Use of forests with due regard to their global environmental significance, as well as taking into account the length of their cultivation and other natural properties…

Furthermore, Article 59: Protection of Rare and Endangered Tree, Shrub, Liana and Other Forest Plant Species states that:

> For purposes of preserving rare and endangered tree, shrub, liana and other forest plant species listed in the Red Book of the Russian Federation or the Red Books of the Subjects of the Russian Federation, it may be prohibited to implement activities with adverse impact which will or can lead to reductions in populations of such plants and (or) deterioration of their habitats, or restrictions may be imposed on such activities (Forest Code, 2007).

However, the Forest Code cannot be considered as the final step of the process from an environmental perspective, and further progress is required. For example, the drafting of more than 50 bylaws is needed and the new Forest Code does not require Environmental Impact Assessment (EIA) of forest management plans and other environment related activities. Putting these inadequacies aside, the Code will play an immediate role in forest biodiversity conservation as well as in other areas in the forest sector.

Unfortunately, the draft Forest Code was not in the public domain during its development. The urgency with which the Code passed the second and the third hearings (less than a month) demonstrates the lack of public consultation.

The federal authorities' intentions seem to be directed at making the Forest Code suitable for solving current problems in the forest sector, such as:

- The low level of forest utilization with timber harvesting currently at 23–25% of the available annual cut (AAC): new forest designations, including forest reserves reduce the available annual cut calculated for the country as a whole.
- Low profitability: long-term leasing has been introduced with forestry operations delegated to the leaseholder.

- Lack of good management practice in the regions: there has been a partial delegation of power and responsibilities to the regions, including forest fire protection and pest control.
- Other problems in the forest sector: administrative and economic functions that used to belong to forest management units (lekhozes) have been separated.
- Illegal logging and trading of wood: a variety of actions at federal and regional levels have been initiated, including site monitoring using aerial photography and satellite imagery.
- Limited innovation and investment activities: a new Article, designed to increase the competitiveness of forest industry by means of investment attractiveness, has been developed.
- Social issues: these are reaching a critical position in the majority of forest regions as a result of low salaries and high levels of unemployment.

These changes are needed because roundwood export has increased from 20 million m^3 in 1998 to more than 30 in 2002 and reached 48 in 2005 (Burdin, personal communication 2006: The concept of forest industry development in the Russian Federation). Between 1991 and 1998 the decline in industrial production in Russia was 54% as a whole and 64% in the forest sector. The significance of this level of decline is apparent, for example, if compared to figures for the Great Depression in the USA (1929–1932: 33%) and in the former USSR during World War Two (1941–1945: 25%).

Reconciling Energy Development

The situation in the timber industry is complex, although recent changes are apparent. During the St Petersburg International Forest Forum (9–13 October 2006), the future of the forest sector was discussed in detail. The forest sector is still export oriented and current demand and supply in Russia are unbalanced because, increasingly, forests are at a distance from the main processing facilities. As a result of the new Forest Code most lease agreements will be renegotiated, raising concerns because large oil, gas and metallurgy businesses have recently demonstrated an interest in the forest sector. The view of the traditional forest industry is that it is not ready to compete with these other sectors. These concerns arise because, for the first time, the new Forest Code separates the timber (or other resource) in the forest from the land on which it grows, making forests liable to land-use change and other manipulations. The whole Russian economy is in a state of flux as a result of changes in property rights, although federal ownership of forestlands is declared in the Forest Code. From an environmental perspective, it is difficult to predict the full implications of the new Forest Code.

Other National Programmes in Russia, particularly for new housing, could help the forest sector by increasing demand for timber. Energy supply for these houses, particularly in remote areas, could also benefit the sector through an increased utilization of woodfuel. As part of its commitment to the UNFCCC and the Kyoto Protocol, Russia will increase production of biofuel as a renewable energy source.

Although renewable sources of energy such as solar, wind, oceanic, hydroelectric, geothermal and biomass contribute much less than energy production from fossil fuels, more than 5 million families in Russia use firewood, consuming 50 million m^3 annually (Energy Strategy, 2003). The vast extent of Russian forests and quantity of waste from timber processing facilities will help towards the development of a bioenergy industry. It is expected that about 20 new facilities making wood-pellets will be in operation within the next 2 years. This represents rapid progress, because the Russian Energy Strategy, adopted in 2003, made no mention of bioenergy.

Bioenergy and its links to the Kyoto Protocol is specifically mentioned in the new Forest Code, with a separate Article on forest plantations – Article 42: Establishment and Use of Forest Plantations:

1. Establishment and use of forest plantations is an entrepreneurial activity involving cultivation of forest stands of definite species (targeted species).
2. Forest stands of definite species (targeted species) are man-made forest stands which supply wood with preset properties.
3. Forest plantations may be established on the forest estate lands and lands of other categories.
4. Forest parcels shall be leased out to citizens and legal persons for the establishment and use of forest plantations in accordance with this Code, and parcels of land shall be leased to them for the same purposes in accordance with the land legislation.
5. It shall be permitted to cut and utilize stands within forest plantations without conditions being applied.

This means that forest plantations established on any land will be the property of the person or legal entity that made it.

European Union and Russia

The European Union and Russia have a long history of good relations in many sectors of economy, particularly energy, where Russia is the largest exporter of oil and natural gas to Europe (EU:25–63%, EC:30% of oil and 50% of natural gas). The export of timber is less important in economic terms, although roundwood from Russia amounts to 40% of total imports into the EU.

Technical assistance and bilateral activities in the forest sector are linked to the export of machinery and technologies from Europe (primarily Scandinavia), forest genetics research and development and the exchange of concepts and ideas. The new Forest Code commits Russia to undertake a national forest inventory (NFI), and there is an intention to invite experts from Finland and Sweden, as well as the USA and Canada, to develop this NFI system.

Russia contributes to ECONET – a European system designed to support biodiversity conservation in diverse ecosystems based on the system of protected areas of different ranks – and it is implemented in European Russia. In

2007, Russia will join the Countdown-2010 initiative, alongside many other projects with financial support from the EU, including biodiversity conservation, forest growth modelling, studies of public involvement in forest management and climate change.

Russia is also committed to the Europe and North Asia Forest Law Enforcement and Governance (ENA FLEG) process that could help countries to counter illegal logging and reduce the damage to forest biodiversity, having signed up to the initiative in 2004 and held a Ministerial Conference in 2005.

Conclusions

The length of this chapter necessarily limits its scope and some significant topics of forest biodiversity conservation are not covered, including protected areas, invasive species, intermediate timber harvesting impact, deforestation, genetic resource preservation, migration of species and changes in forest landscapes. However, it is clear that climate change and human impacts on the biosphere and biodiversity are well-recognized phenomena and could be considered as drivers of forest tree species extinction.

Many initiatives to halt biodiversity loss, including the EU action plan, IUCN Countdown-2010 initiative have been established. There is also widespread appreciation that environmental criteria should be considered in any disturbance of forest biodiversity, be that land-use change or the introduction of genetically modified plant material, for example.

Russian forests, due to their size and location, play an important role in the maintenance of the global biosphere, while the biodiversity associated with the vast extent of protected forest areas in Russia are also of global significance.

Climate change could impact on all forests in the world, but Russian boreal forests and their biodiversity are under particular threat due to the question of the long-term future of the vast regions of permafrost. Global warming might initiate melting of frozen soils that, in turn, could bring about changes in the hydrological regime (and consequent GHG emissions), vegetation types, loss of boreal biodiversity and the appearance of novel pathogens.

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International Forest Policy and Options for Climate Change Forest Policy in Developing Countries

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Introduction

International and multilateral negotiations on issues related to forests and deforestation have, in the past, experienced numerous barriers to the establishment of a practicable international forestry policy agenda. Interested parties have included the baggage of material interests and ethical principles in the negotiation of potential multilateral agreements addressing forest conservation and sustainable forest management, with poor results as a consequence. Ethical and other subjective factors include sovereignty, right of access to natural resources (generally to foster economic development) and poverty reduction. These factors interact with material interests that are shaped by prevailing trade norms which, in many cases, do not conform with the classical economic premise (on which current international trade agreements are based) that free trade leads to the optimization of social benefit *per se*. Material interests that have developed in this environment include corporate interests in forest utilization, which shape governments' positions through pressure groups, and uncertainty in the cross-boundary effects of deforestation. This chapter explores how these competing interests have shaped international negotiating processes on climate change and forestry policy in developing countries and impeded a successful conclusion. Cost-effective options for progressing these processes are also outlined.

The International Forestry Policy Agenda: Multilateralism as its Least Common Denominator

In a study of the ineffectiveness of global forestry politics (Dimitrov, 2005), the question of the causes of this ineffectiveness was raised, while observing that the

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repeated failure at launching forest policy coordination is particularly notable given the prominence of deforestation in public discourse. Forests, in particular, are symbolic of the natural environment and their degradation resonates with the public. In an age of strengthening norms of multilateral environmental management, we might expect that if obscure ecological problems such as persistent organic pollutants can trigger treaty formation, then the probability of a policy agreement on forests, with their symbolic value and public resonance, would be high.

Forest negotiations were complicated by process-related and political factors from the start. The plan to include negotiations for a forest convention on the agenda for the 1992 UNCED was abandoned at the preparatory stage due to acute disagreements between governments on the need for such a treaty. While the USA, Canada and European countries emphasized the principle of global responsibility in preserving forests, developing countries stressed the sovereign right to utilize natural resources and, as a consequence, no requirement for an international framework for forest conservation. The Rio conference produced only the *Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of all Types of Forests*. After Rio, Parties to the 1983 International Tropical Timber Agreement considered expanding the scope of the treaty to include boreal and temperate forests. The USA and the European Union objected strongly to changes in the treaty and succeeded in preserving its exclusive focus on tropical regions. Developing countries considered such a position as duplicity: the North was pressing them to protect tropical forests but was unwilling to reciprocate with temperate and boreal forests.

During debates at the UN Commission on Sustainable Development in April 1995, countries recognized the need for an international dialogue dedicated exclusively to forests. To this end, they established the Intergovernmental Panel on Forests (IPF), a 2-year *ad hoc* forum for discussion. The IPF convened four times between 1995 and 1997, but countries could not agree on major issues such as the need for a convention or financial assistance to implement forest policies in developing countries. At the UN General Assembly, a decision was made to continue the policy dialogue and establish an *ad hoc* Intergovernmental Forum on Forests (IFF), although this was widely perceived as simply a continuation of the IPF.

The most controversial issue at the IPF and the IFF was whether to seek an international policy agreement, and the negotiations were characterized by virtually complete stagnation. Throughout the eight rounds of talks, during sessions of the IPF and the IFF, the positions of the main protagonists in the negotiations remained virtually unchanged. The treaty debate was dominated by financial matters. Developing countries were afraid that, if they committed to a binding agreement, the North would not provide resources for its implementation and leave them without means to comply with their agreed obligations.

Remarkably, most non-governmental organizations (NGOs) at the negotiations bitterly opposed an international convention. In 1992 they had been enthusiastic supporters of a treaty but their position changed in the mid-1990s. The counter-intuitive NGO position was motivated by two considerations. First, they felt negotiations would divert attention from existing initiatives and suspend sustainable forest policies while governments and industries were waiting for the resulting convention. Second, they were sceptical about the content of any resulting treaty. Witnessing the deep disagreements among governments and their refusal to pledge new financial resources for forest policy, the NGOs calculated that a treaty would be weak and would serve to legitimize the exploitation of forests.

The denouncement of the negotiating process came at the IFF's last session in early February 2000. After long hours, consensus could not be reached and the final decision amounted to rejecting the concept of a forest convention. Instead, the IFF decided to create the UN Forum on Forests (UNFF), an international institution with universal membership that reports to the UN Economic and Social Council. The design of the institution, not necessarily equipped with the tools for international policy enforcement, responded to the convergence of disparate preferences. Since then, UNFF resolutions and recommendations have contained all the right ideas but commit no party to action. The adopted documents allow countries to set their own priorities and do not require them to report on policy implementation. In short, this global institution is collectively and purposefully designed to be ineffective: it has no mandate for decision making, allows individual countries to choose what they want to do, does not provide them with financial assistance to do it and has no right to hold them accountable for the results of their action.

The sixth meeting of the UNFF, in February 2006, decided to negotiate, conclude and adopt a non-legally binding instrument (NBI) applicable to all types of forests at UNFF 7. Several consultative processes were established to ensure that this result is achieved within the year. The UNFF also decided that the effectiveness of the international agreement on forests would be reviewed in 2015 and, on this basis, a full range of options will be considered, including a legally binding instrument on all types of forests and strengthening the NBI arrangement. The scope and effectiveness of the NBI will be decided by negotiations throughout the year, and it could signal the beginning of the end of a system that promotes endless dialogue without commitments. Instead, a framework may be developed that, albeit non-legally binding, still succeeds in promoting an improved implementation of the principles of Sustainable Forest Management. This would depend not so much on the design of the UNFF *per se*, but on the direction of the convergence of interests of the Parties involved, in relation to the theoretical framework detailed in the following section. The dynamics of the process could produce a breakthrough, or fall again in the vicious circle of invalidating every single effort to coordinate international forest policy in a multilateral forum.

Norm of environmental multilateralism: an explanation of ineffectiveness of multilateralism in forests

Given the derisory outcomes of notable hard negotiation processes, it is legitimate to ask why such difficulties were encountered in establishing an international policy framework on forests, and to explore the contributory factors. It is outside the scope of this chapter to attempt a thorough explanation of the process but, at least, a basic understanding of the issues can be developed by outlining some of the key barriers to an effective outcome.

The focus of the analysis should be set in what is called the norm of environmental multilateralism (NEM), defined as *the collective expectation that governments address global ecological issues in a collective, multilateral manner*. Unlike relatively narrow norms focused on individual environmental agreements (e.g. the treaty to manage international trade with endangered species: CITES), NEM is a broad norm that operates across various environmental issues and is not necessarily contingent on the existence of legal instruments. In this respect, it appears that NEM has not been sufficient to facilitate the creation of an operational forest policy regime. Hence, the collective decision not to create a forest convention was shaped by a range of factors including other norms (market-based norms of free trade and development), vested corporate interests in forest exploitation, scientific uncertainty in the cross-border consequences of deforestation, and shared doubts about the added value of co-ordinating forest policy.

This demonstrates the limits of normative influences: norms may empower regimes by reshaping state interests but they rarely 'cause' policy behaviour such as regime formation. In this context, a normative '*logic of appropriateness*' guides states to participate in multilateral policy deliberations (Dimitrov, 2005), rather than to establish normative guidelines with a sense of urgency.

According to this analysis framework, the current stalemate in international forestry negotiations has been produced by a combination of material and ideological factors. Socioeconomic interests in forest exploitation reduce the incentives for policy coordination. At the same time, NEM makes it prohibitive to disengage from international discussions on a prominent ecological issue. As a result, this norm holds governments hostage in hollow institutions deliberately designed to be idle. Global forestry institutions provide no mechanisms for governance – not because they fail in implementation but because they are 'decoys', deliberately intended to pre-empt governance.

Specific factors that pre-empt the formation of a normative framework for forest conservation are various. The socioeconomic costs of protective policies are high because forest utilization is a complex cross-sectoral issue that affects a number of socioeconomic realms, including agriculture, timber industries and hydroelectric energy supply. Concerns over relative gains and losses are also acute since the geographical distribution of forests is uneven and a global treaty would impose unequal obligations on some nations with, for example, those with extensive forest cover bearing a heavier burden.

The analysis concludes that governments agreed to create the UNFF not with substantive purposes in mind but, merely, as an alternative to the zero-policy option. Governments cannot afford to give the impression that they are not busy 'doing something' about a highly symbolic environmental issue such as deforestation. The combined influence of norms and material interests effectively shepherds nations into creating a feeble institution, from the point of view of the practice of international forest policy. Hence norms explain the creation of the UNFF while material interests explain its particular design.

It would also be useful to see how these factors, which affect the effectiveness of the UNFF in defining the forest conservation normative, will be translated into the new NBI, and into the associated negotiation process. What seems clear is that the same logic of appropriateness led to the decision to negotiate and conclude a non-legally binding arrangement rather than a treaty on forest conservation.

How does NEM affect the discussion of forests at the UNFCCC?

The same logic of appropriateness guided discussions at the beginning of negotiations on forests at the UNFCCC. In its preliminary section, the text of the UNFCCC states that the Parties are aware of the role and importance in terrestrial and marine ecosystems of sinks and reservoirs of greenhouse gases (UN, 1992). Article 4 of the Convention, which details the commitment of the Parties to the Convention, mandates in its paragraph 1(d) that Parties should '*promote sustainable management, and promote and cooperate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests and oceans as well as other terrestrial, coastal and marine ecosystems*' (UNFCCC, 2005).

However, no further measures were implemented in the UNFCCC to promote sustainable management of sinks and reservoirs of GHG, nor to conserve or enhance them. When the time came to negotiate an amendment to the UNFCCC, pursuant to Article 4, paragraph 2(d), which led to the Kyoto Protocol (KP), no measures for the promotion of sustainable management of these sinks and reservoirs, nor to their conservation and enhancement, were considered. These actions would have been an effective means to engage non-Annex I countries in mitigation of climate change at a relative lower cost of compliance and, maybe, constitute a sufficiently good 'bait' for the US to engage the KP more readily. In fact, in the last hours of COP6 at The Hague, this was one of the deal breakers that the USA was expecting to get from the European Union, together with a loose compliance system and some political indication of a 'more substantive participation' from non-Annex 1 countries.

A recent document published by the Netherlands Programme on Scientific Assessment and Policy Analysis (Trines *et al.*, 2006) highlights that, although the UNFCCC calls for a comprehensive approach addressing the sources and sinks of all GHGs, '*the treatment of emissions and removals from land use, land-use change and forestry (LULUCF) under the Kyoto Protocol (KP) and its implementing rules, the Marrakech Accords, is rather fragmented and sometimes considered flawed*'.

Why are Forests at the UNFCCC Treated with More Relative Effectiveness?

As a result of different dynamics of NEM in the UNFCCC and the KP, the Parties were forced to treat LULUCF in a more proactive manner, particularly for developing countries, for a number of reasons:

- The high certainty of the consequences of deforestation and associated carbon balance on the global climate system, compared to the more general impacts of deforestation on global ecosystems.
- The drive from prominent Parties such as the USA (on account of its high level of GHG emissions) to include LULUCF activities among the options included in the CDM, for reasons of cost-effectiveness.
- The insistence, since COP4, of a group of Parties to include LULUCF activities in the CDM, on account of their low capacity to participate in 'energy' CDM projects; this internalization also affected the position of some Parties, reducing their resistance to the inclusion of LULUCF activities in the CDM.
- The technical nature of the issues associated with LULUCF activities for Annex I countries, which also permeated the alternatives for the use of LULUCF activities in the CDM.

The treatment of forests: a recurrent debate

The last-minute refusal of the USA to sign an agreement at The Hague, and the subsequent withdrawal of the country from the KP, sealed the fate of the inclusion of reduction of emissions by deforestation in the first commitment period. However, through subsequent negotiations, one of the options that seemed impossible just two years earlier was included in the CDM, following a 'concession' from the European Union – namely, afforestation and reforestation activities.

However, the discussion about reducing emissions by deforestation is subject to the same perverse logic of appropriateness. While everybody involved recognizes the importance of this source of emissions, the diversity of interests impedes a cost-effective resolution of this issue because the debate is charged with ideological motivations. A number of subjective arguments thus permeates the discussion:

- *The classical emotional value of forests.* No Party or stakeholder can afford to appear as acting contrary to principles of forest conservation.
- *The poignant issue of sovereignty.* No developed country can be seen as acting against the dominion of a developing country unless they are willing to be accused of 'neo-colonialism'.
- *The unavoidable principle of being climatically sound.* No developing country would like to be accused of undermining the effectiveness of the KP or the international policy framework for climate change and, although issues of avoiding or controlling leakage are technically feasible, the debate about these issues is highly emotional.
- *The necessity of being environmentally and socially sustainable.* Activities aimed at reducing emissions caused by deforestation are generally more strictly assessed against sustainability criteria, and thus continuously need to demonstrate that they have overcome their original transgression from acceptable practice.

Reduction of emissions by deforestation: a phantom travels through the convention

Despite its temporary defeat, the idea of reducing emissions through avoided deforestation has turned out to be a recurrent theme, as have financial or market incentives for the promotion of conservation and enhancement of carbon reservoirs. As a consequence, the concept of reducing deforestation and receiving compensation (monetary or in emissions rights) will continue to be debated until it is included in the framework of the international climate negotiations. Until that time, it will be a phantom travelling through the corridors of the COP/MOPs. The options presently at the table for including reduction of emissions through avoided deforestation in developing countries (REDDC) are summarized in the following section.

All the requirements for the inclusion of compensation for the reduction of deforestation and its associated emissions come from a principle that is sound and objective, namely, that the management of carbon fluxes in terrestrial and marine ecosystems is an important part of any effective legal climate regime. The motivations may vary, but the interested parties will always demand that the value of the conservation of carbon reservoirs is, as a minimum, equated to the benefits of alternative uses that have associated environmental and social costs in the form of GHG emissions. Under present conditions, this is only achievable through market instruments, either alone or in conjunction with other measures.

One of the recurrent arguments is that

> Adopting an instrument [compensated reductions] of this kind in the context of the Protocol would promote adoption of policies for controlling deforestation in developing countries, and would allow tropical nations to take a meaningful role in preventing dangerous interference in the climate system… The future of the Kyoto Protocol is indeterminate, but the contribution of tropical deforestation to global climate change is not (Santilli *et al.*, 2005).

Continued deforestation at current rates in Brazil and Indonesia, alone (see Table 22.1), would equal more than twice the annual emissions reduction target for Annex I countries in the Kyoto Protocol and subsequently ratified (150 MtC yr^{-1}; UNFCCC, 2007). The combined effects of clearcutting and logging (discounting forest regrowth on abandoned land) released between 0.8 ± 0.2 and 2.2 ± 0.8 GtC yr^{-1} in the 1990s, equivalent to 10–25% of global, human-induced, emissions. These emissions may be increasing. Annual deforestation in Indonesia increased from 17000 km^2 over the period 1987–1997, to 21000 km^2 in 2003, with carbon emissions similar to those in the Amazon. These estimates do not include the effects of tropical forest fires on carbon emissions, which are much more difficult to measure.

The Options on the Table

Negotiations over reducing deforestation in developing countries are always hindered, to a certain degree, by the same logic of appropriateness that renders other international fora on forests inoperative, and that delay their consideration

Table 22.1. A comparison of carbon emissions from fossil fuel, tropical deforestation and forest fires (source: modified from Santilli *et al.*, 2005).

Country	Source	Carbon emission (GtC yr^{-1})
Brazil	Fossil fuel (year: 2002)	0.09
	Deforestation	0.2 ± 0.2
	Forest fire (El Niño year: 1998)	0.2 ± 0.2
	Forest fire (non-El Niño year: 1995)	0.2 ± 0.2
Indonesia	Fossil fuel (year: 2002)	0.08
	Deforestation	0.2 ± 0.2
	Forest fire (El Niño year: 1997–1998)	0.4 ± 0.5
	Peat fire (El Niño year: 1997–1998)	0.2 ± 0.2
Global	Fossil fuel	6.3 ± 0.4
Tropical	Land-use change	0.6 ± 0.2 to 2.2 ± 0.8
Global	Fire (El Niño year: 1997–1998)	2.1 ± 0.8

under the UNFCCC and the KP. However, the relative importance of deforestation in global emissions cannot be denied, must be internalized and hence the drive to consider these emissions in further negotiations of the climate regime is stronger than resistance to their inclusion. As a consequence, those countries that are resistant to the idea of including any reductions in emissions in the LULUCF sector in any of the defined or foreseen market instruments will develop proposals that introduce compensation or rewards, but that avoid market instruments.

Since COP12 / MOP2, three options have been presented:

1. The proposal by the Government of Brazil, which essentially advocates the creation of a fund to reward the reduction of emissions attributable to deforestation in developing countries, introducing financial assistance from a fund financed by voluntary contributions from, principally, Annex I Parties; in this proposal, Parties that participate voluntarily, but miss the target established for a given year, would be excluded from receiving proceeds from the fund in the next year they reach the compliance level.

2. The proposal(s) by the Rainforest Coalition, which seems to prefer market instruments, but will settle for the creation of an Annex to the Kyoto Protocol by which non-Annex I countries would be bound by (voluntary) binding commitments for reduction of emissions by deforestation, and will be allowed to trade any emissions in surplus of this level; in this proposal, the baseline would be set at the national level, that is calculating the national rate of deforestation, and any reduction of this rate will be deemed additional.

3. A third proposal from Latin American Parties favours participation through market mechanisms, but is flexible in the choice of the baseline, which could be project-based, regional or national–sectoral, in accordance with the specific characteristics of each participating country; this proposal would be voluntary and would not require binding commitments or a new Annex to the Protocol.

These three proposals can be translated into the following five instruments:

- A fund for the promotion of activities for REDDC.
- The inclusion of RED in the CDM, as a project-based activity.
- The inclusion of RED in the CDM as a programmatic activity (programmatic CDM, which is being developed by the Executive Board and would include two or more project activites).
- The establishment of a market mechanism through a legally binding agreement (new Annex to the Protocol), with national-sectoral baselines.
- The establishment of a non-legally binding market mechanism through an independent ('additional') Protocol to the UNFCCC.

The advantages and disadvantages of these alternatives, plus an initial assessment of its climatic 'integrity', are analysed below.

Advantages and disadvantages of the proposed instruments to counter deforestation

A preliminary assessment of the five options listed above was conducted against a predetermined set of criteria, which included the legal requirements relating to: (1) the requirement to ratify an amendment to the UNFCCC or KP to accommodate the instrument in the existing climate policy regime, (2) the overall socioeconomic efficiency of the instrument and its ability to assign financial resources via a 'price' or allocation of a financial reward for compliance, (3) the level of additionality or effective mitigation which is additional to existing commitments or simply offsets against them, and (4) the requirements of technology transfer and capacity building for monitoring and control. The results, which could be further elaborated, are given in Table 22.2.

It is important to highlight that on the basis of current knowledge and practice, leakage is more of a perceived risk than a technical reason for rejecting any instrument. For any instrument that is eventually adopted, leakage can be avoided, minimized or discounted. However, due to the diversity of economic, sociocultural, political and biophysical characteristics of the countries involved, one important point to highlight is that there is no 'silver bullet' that will suit all non-Annex I countries willing to take action in this area, even if the instrument is voluntary and non-legally binding. Furthermore, each of the instruments discussed here only require participation from willing Parties raising the question as to whether a single instrument is the optimal design for the inclusion of RED into the climate negotiations.

Cost-effectiveness: a major argument for differentiated policies in developing countries

Different countries have different patterns of deforestation and when patterns are similar sometimes the drivers of deforestation may be different. As Fig. 22.1 shows, the magnitude of deforestation in Africa, and thus the loss of carbon

Table 22.2. Advantages and disadvantages of the options for reducing deforestation.

Option	Advantages	Disadvantages
1 Voluntary Fund (Brazilian proposal)	● No negotiation required for linkages to carbon market ● Minimizes leakage ● Additional to KP actions ● Moderate requirements for TT and CB	● Levels of funding uncertain ● Decreasing trends in ODA ● Inconsistent rewards: socioeconomic efficiency not built-in
2 Inclusion in the CDM, project-based	● No amendments to KP required ● Straightforward decision process for inclusion ● Moderate to high requirements of TT and CB ● Price determined by market conditions ● Relative economic efficiency	● High requirements of political negotiation required ● Not additional to KP, only offsets ● Equity (regional distribution) not built-in ● Perceived difficulties with leakage
3 Inclusion in the CDM, sectoral	● No amendments to KP required ● Moderate requirements for TT and CB ● Price determined by market architecture ● Relative economic efficiency ● Limited concerns with leakage	● High requirements for political negotiation required ● Programmatic approach to CDM not defined, not straightforward ● Not additional to KP, only offsets ● Equity (regional distribution) not accommodated
4 Legally binding market mechanism through new Annex to the KP	● Price determined by market architecture ● Relative economic efficiency ● If feasible, good regional distribution ● No leakage?	● Amendment to KP required ● Possible protracted negotiating process ● Legal difficulties over linkage to carbon market and possible incompatibility ● Perception of undermining of KP ● High requirements for TT and CB
5 Non-legally binding market mechanism through additional Protocol	● No amendment of KP required, shorter negotiating process ● Price determined by market architecture ● Relative economic efficiency ● If feasible, good regional distribution ● Limited concerns over leakage	● Political agreements needed in a possible package ● Legal difficulties over linkage to carbon market ● Parallel monitoring process required ● High requirements for TT and CB

ODA: Official Development Assistance; TT: technology transfer; CB: capacity building.

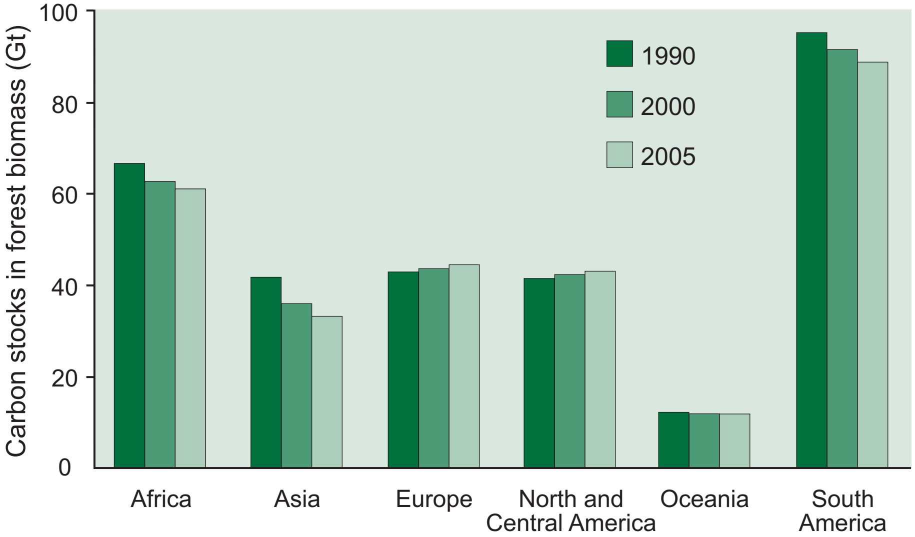

Fig. 22.1 Loss of carbon stock in Africa compared to other regions (source: FAO, 2006).

stocks in carbon biomass, has been generally smaller than in South America. It should be noted that the figures for deforestation given in Fig. 22.1 represent absolute loss rather than loss as a proportion of total forest area. Nevertheless, deforestation in African countries remains relevant to their economies (see Table 22.3). It has been suggested that a market instrument will benefit those countries with a high rate of deforestation more than those with a lower rate. Countries in the Congo Basin are generally perceived to have low rates of deforestation, but Table 22.3 shows that this is not necessarily the case. Formal economic analysis provides further insight into the issue and how it might be addressed.

Table 22.3. Magnitude of deforestation in Africa (source: author's elaboration based on *Global Forest Resources Assessment, 2005*; FAO, 2006).

Country	Net deforestation in thousands ha yr^{-1}, 1990–2005
Brazil	2821.93
Indonesia	1871.47
Sudan	589.04
Democratic Republic of the Congo	461.40
Zambia	444.80
United Republic of Tanzania	412.27
Nigeria	409.67
Mexico	318.53
Zimbabwe	312.93
Cameroon	220.00

Economic theory leads to two main policy options regarding the reduction of GHG emissions. These options depend on the relationship between the benefit that society receives from the reduction (in GHG emissions) compared to the cost that will be incurred to achieve it. Economists look at marginal costs and benefits (being the cost/benefit of one additional unit). These change over time with earlier changes being valued higher (and/or costing less), and often easier to achieve than later ones. Plotting these marginal costs and benefits will give curves, which reflect this changing relationship. Where the benefit to society is greater than the cost of reduction, this surplus can be efficiently traded in a market, where producers are given quotas and these are traded to achieve the emissions reductions through the most effective means. However when the cost to the producer (of the GHG emissions) exceeds the benefit they achieve, there is no incentive to take action and, in this case, a price incentive such as a tax or a subsidy could be more effective (Philibert, 2006). The analysis by Philibert did not extend to subsidy, but such a development might be an appropriate direction for future research. As cited by Jacoby and Ellerman, '*the key to the choice is whether cost or benefit changes more rapidly as the level of emission control is varied*'.

Even so, where policies and instrument do not benefit countries that have had low deforestation rates in the recent past, but are facing increased pressures for forest clearance on account of various economic, political and sociocultural drivers, the possibility of using and combining more than one instrument should be an option.

First, market instruments should be set to what is termed 'a methodology base to reward good past behaviour', so that countries with a low rate of deforestation should be able to benefit from incentives to reduce deforestation. To accomplish this through carbon markets, baselines should take into account:

- sociocultural variables that prevent deforestation, and imminent pressures on these variables that might reduce their effectiveness;
- mounting economic pressures over land use that might lead to deforestation in the near future;
- the changing relationship between marginal benefit of standing forest versus alternative uses.

Alternatively, a combination of instruments, as suggested by Philibert (2006), would enhance the effectiveness of the instruments to reduce emissions from deforestation, for the following reasons:

1. The high variability of the differential between marginal benefits and marginal costs in different countries, and for different instruments; more detailed research would strengthen understanding of this variability.
2. Highly diverse conditions of application of the instrument, among them political norms, institutional architecture, market(s) configuration, sociocultural perceptions and biophysical background related to soil characteristics, hydrological regime and species.
3. Effectiveness of the combination of instruments, including the possibility of using only one instrument, and the conditions of involvement of local stakeholders and indigenous peoples.

4. The appropriate utilization of diverse instruments based on the limits and ranges for which each is most effective, including price caps and price bases, subsidies or taxes after price caps, etc. In effect, the effectiveness of the instruments is enhanced by variations in conditions of their utilization.

Given the multiplicity of circumstances and material interests of developing countries that are likely to be involved in climate change mitigation activities in the forestry sector, it is advisable to put before them a full array of instruments available to make this policy option more cost-effective. In the practical world, however, and as a result of the dynamics of negotiations, it is likely to come down to a choice between one market instrument and one subsidy instrument (fund). Even then, the availability of two alternatives might enhance not only participation but also the efficiency of participation, whether each country chooses only one instrument or a combination of both to tackle its GHG emissions by deforestation.

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Addressing Deforestation and Forest Degradation Through International Policy

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Introduction

Accounting for approximately 30% of the world's land mass, forests provide a wide range of economic, social, cultural and environmental services. An estimated 800 million people live in or around forests and use forest resources for fuel, food, medicine and income; of these, 70 million are indigenous peoples living in remote areas who depend completely on forest resources for their livelihoods. Forests also contribute significantly to populations living further afield through the provision of a wide range of forest products and recreational opportunities, as well as environmental services such as watershed protection and contribution to local and global climate control and habitat for a host of flora and fauna. At the same time, growing demand for forest products and competing land use have resulted in continued, extensive and rapid rates of deforestation and forest degradation. In turn, these have contributed to local and trans-boundary environmental damage, detrimental impacts on land sustainability and productivity as well as on local communities, loss of biodiversity and release of carbon emissions into the atmosphere.

With growing concern regarding the effects of climate change on the earth's atmosphere and environmental stability as well as the economic costs of mitigation (Stern, 2006), the contribution of deforestation to emission of greenhouse gases has gained particular prominence in policy circles of late. Tropical deforestation releases approximately 3.8 billion tonnes of carbon dioxide (CO_2) a year (Achard *et al*., 2004) and accounts for about 20% of human-generated CO_2 emissions (House *et al*., 2006), affecting populations at a global scale.

International attention to ongoing deforestation and its effects on climate change are reflected in recent decisions taken by countries at the intergovernmental level. At the sixth session of the United Nations Forum on Forests (UNFF) in February 2006, countries agreed to set four Global Objectives on Forests, the first of

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which is '… to reverse the trend of loss of forest cover …' (United Nations 2006); in other words, to not only stop deforestation but instigate a transition to overall forest cover gain. Within the context of the United Nations Framework Convention on Climate Change (UNFCCC), Papua New Guinea, Costa Rica and others introduced a proposal in December 2005 to create financial incentives for countries to avoid deforestation. The proposal is currently under discussion and will continue to be discussed for at least one more year. Taken together, the political will to reverse deforestation trends coupled with a financial mechanism to support that goal could do much to benefit both local and global populations. Yet the extent, drivers of and incentives for deforestation and degradation vary significantly from region to region and are often very locally specific. Finding policy solutions that effectively address these issues will require a nuanced understanding of the varying nature of the root causes of deforestation combined with a long-term commitment at both the national and international levels.

Drivers of Deforestation and Degradation

Deforestation and forest degradation are the result of a very complex confluence of actors, interests and circumstances. Such drivers range from the changes in global markets that affect the demand for timber or agricultural products to the need of local communities for land to use in subsistence agriculture. A diverse set of changes in, for example, growth of timber demand, technology, access to roads and transport, prices of agricultural inputs, industrial development and fluctuating labour markets at the local and national levels, can have both negative and positive impacts on the rate of deforestation (see Chomitz *et al*., 2006). Traditional tools of rural development such as creating access to capital and securing land tenure can also have either positive or detrimental effects on forest conservation depending on whether the primary markets available are for forest or agricultural products (Merry *et al*., 2002).

The actors engaged in deforestation and degradation also vary significantly from region to region as well as even from one locale to another. For example, while the majority of deforestation and degradation in Latin America is a result of agriculture and non-sustainable extraction of timber, with 45% of land-use change being the conversion of forests to large-scale permanent agriculture, deforestation is primarily driven by small-scale permanent agriculture and charcoal harvesting in Africa, accounting for about 60% of land-use change there (United Nations Food and Agriculture Organization, 2001). In the boreal and temperate forests of North America, Europe and the Russian Federation where deforestation is still occurring, unsustainable extraction seems to be the primary driver. As in Latin America, a significant portion of deforestation in Asia is driven by large-scale permanent agriculture (30% of land-use change) but unsustainable extraction plays a much greater role in this region. Degradation is often a result of extraction of high value trees. If the density of high value trees is high enough, such extraction can lead to deforestation even in the absence of agriculture. Though land use tends to be more clearly segregated in other parts of the world, there may be many interests competing over the same piece of territory in Asia. One particular area may be disputed by a combination of small commercial farmers, large timber and plantation interests and long-residing local populations (Kaimowitz and Angelsen, 1998), indicating the need for complex policy measures.

There is a strong relationship between population densities, rate of change of population, market access, soil quality and secure tenure on one side and changes in land use on the other. Plate 11b and c shows forest cover for Latin America and Asia. Plate 11a shows savannah cover for Africa (as savannah is the predominant landscape type in that continent and is thus more illustrative). Chomitz *et al*. (2006) use three different forest landscape types to better understand these interactions:

- remote forests, to which access is severely limited and forest cover remains predominantly old-growth;
- forest edge, an area with enough access to agricultural markets to drive expansion;
- forest–agricultural mosaics, established agricultural lands interspersed with woods that are often relatively close to urban centres.

The remote forests have extremely low population density (at the most remote, one person per 10 km^2) and are predominantly inhabited by indigenous peoples and other small communities. Covering more than 10 million km^2, Latin America and the Caribbean have the highest total forest area in the tropics, exceeding that of Africa and Asia combined, and also the most remote forest area. Communities living in such areas are far enough from urban centres that transportation costs do not make agriculture a viable form of commerce and even extraction can bring relatively low returns. These communities often experience the greatest depth of poverty, characterized by a lack of access to basic education, health care, sanitation and other services. Low population densities coupled with distance from administrative centres and poor communication often translate into a lack of voice in state and national affairs and further marginalization. Because of the relatively small rates of conversion, policy interventions in these areas may be more effective in alleviating poverty by providing services and access to governance structures than in impacting deforestation and degradation.

The areas at the forest edge contain lands that are rapidly increasing in value because of their relative proximity to an urban centre and, thus, greater market access. They are predominantly inhabited by settlers undertaking small-scale conversion or extraction, but can also be taken over by wealthier agricultural, extraction or plantation interests. The frontier is often marked by intense conflicts over resource use and tenure, with settlers struggling to secure at least *de facto* control of the land that they can later sell to larger-scale agriculturalists. In Latin America and Africa, there is a correlation between soil quality and the choice to deforest in these areas, whereas this relationship does not seem to exist in Asia.

In such less remote areas tenure and access to forest resources can have significant impacts on the incomes and livelihoods of the poor. Regulations, sometimes remaining from colonial times, can affect forest use by rural communities. Such rules may impede the gathering of fuelwood, medicine or food from the forest or may inhibit agroforestry. A change in regulations or control of the land and trees can also dispossess the rural poor from access to resources and severely affect livelihoods (Ghimire and Pimbert, 1997). At the same time, areas with open access and unclear tenure arrangements often suffer a 'tragedy of the commons' type of overexploitation and subsequent significant degradation.

Off-farm wages, perhaps in neighbouring plantations, farms or even more distant towns, that are lucrative enough can dissuade smallholders from using forested land for subsistence or low-value crops (Kaimowitz and Angelsen, 1998). Increasing the off-farm incomes of small forest landholders or increasing their potential income from sustainable forest management can provide an opportunity for gains. Though these actors are not responsible for the majority of deforestation and degradation in Asia and Latin America, the amount of land they impact can still be quite significant. Focusing policy on affecting the behaviour of these actors, such as through the creation of community-based forest management systems, can provide a win–win solution: reducing carbon emissions from deforestation while at the same time improving the livelihoods of some of the world's poorest populations.

Finally, the forest–agricultural mosaic lands are usually characterized by permanent agriculture and more stable tenure. They account for a minority of the world's forest estate but contain a substantial portion of its forest dwellers and the highest forest population density, a large share of threatened species, and the bulk of locally valued forest services (Chomitz *et al*., 2006). Such forests are most vulnerable to deforestation for the expansion of large-scale agriculture or the creation of plantations. As the primary actors in such areas are relatively wealthy, and because of the easier access to markets, the decision to deforest is primarily driven by market forces. At the same time, the largest populations of forest-dependent communities live in these areas, often deriving up to one-fifth of their incomes from forest resources (Vedeld *et al*., 2004). Promoting off-farm employment, community-based forest management and agroforestry could be effective policy interventions in this area.

Misconceptions about the role of the poor in deforestation and degradation can result in improper policy. Though some areas are indeed deforested by the poor they are not always the primary actors. For example, a recent World Bank–Global Environment Facility project in Indonesia sought to deter deforestation of Kerinci-Seblat National Park by local communities and thus provided measures to raise their incomes. But the Park contains highly prized hardwoods and the local climate makes it ideal for growing cinnamon. Modest income transfers to the local community did not result in decreased deforestation in that particular locale. A misunderstanding of the drivers at the very local, community level can result in poor policy planning.

Global Forest Policy and Reducing Emissions from Deforestation

There are more than 40 international organizations and more than 20 international agreements related to forests, and no single international institution or instrument has the mandate or capacity to address all aspects of forest policy at all geographic scales. The first global discussion of forests as an environmental resource took place in 1972 at the first United Nations Conference on Environment and Development. A number of international instruments were agreed during the years immediately following the conference, including the Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) and the Convention Concerning the Protection of the World Cultural and Natural Heritage. Most such instruments focused on environmental conservation and protection rather than taking into consideration the socioeconomic importance of, and impacts on, various ecosystems. Forests were considered one part of these multilateral agreements but were not the primary concern.

The continued increasing rate of deforestation as well as the transboundary and international effects of such land conversion turned forests into a fully international issue of concern in the 1980s. The first global consensus on forests was reached by Heads of State in June 1992 during the second United Nations Conference on Environment and Development, colloquially known as the Rio Earth Summit, with the adoption of the Non-Legally Binding Authoritative Statement of Principles for a Global Consensus on the Management, Conservation and Sustainable Development of All Types of Forests, otherwise known as the Forest Principles, and Chapter 11 of Agenda 21, entitled Combating Deforestation. Both Agenda 21 and the Forest Principles outline the ecological and socioeconomic importance of forests, placing an emphasis on national sovereignty in decision making as well as the importance of public participation, capacity building, and creating a national and international enabling environment for conservation and sustainable forest management. Together, these agreements represent the beginning of a more nuanced view of sustainability and environmental conservation at the global level, fully cognizant of the tension between protection and development.

Governments took up the issue of deforestation in the context of the Intergovernmental Panel on Forests and again in 1998–1999 through a highly participatory process culminating in the Global Workshop on Addressing the Underlying Causes of Deforestation and Forest Degradation (United Nations, 1999, 2002) which served as an input to the third session of the Intergovernmental Forum on Forests (IFF) and was discussed at the second session of the UN Forum on Forests. The Workshop, the IFF and the UNFF recognized a wide range and diverse set of underlying causes that determine the drivers of deforestation, most of which are socioeconomic in nature. To name but a few, they include (but are not limited to):

- unsustainable patterns of production and consumption in the developed countries; inappropriate development models;
- deleterious effects of international trade agreements;
- perverse subsidies;
- population growth;
- lack of secure land tenure and rights to forest resources on the part of indigenous peoples and local communities;
- poor governance and lack of transparency in decision making;
- lack of technical capacity and financial resources at the national and local level.

Apart from the resolutions and decisions of these intergovernmental processes, a number of tools have proven useful in assisting countries to identify and address underlying causes and drivers of deforestation. The idea of creating National Forest Programmes (NFP) was a major output of the Earth Summit and NFPs have proven quite effective in facilitating cross-sectoral analysis and a participatory approach to identifying problems as well as formulating, implementing and monitoring policies, strategies and actions. The consultation required to create such a framework for national level policy can be helpful in aligning forests with the wider national development goals and ensuring financial commitments. It is hoped that they would also contribute to and be in line with national poverty reduction strategies. Substantial efforts have also been made to create criteria and indicators for sustainable forest management through nine regional processes involving more than 140 countries. Such processes are useful in helping to create region-specific conceptualizations of what it means for a forest management system to be sustainable. These processes also allow the monitoring and assessment of change in the forests and the effectiveness of policy interventions.

Forests and their role in both mitigating and contributing to climate change have also been a topic of discussion within the context of the UN Framework Convention on Climate Change since its inception in 1992. The framework convention requires reporting of greenhouse gas emissions by its parties but allows for carbon sequestration by forests to be subtracted from the totals, thus identifying forests as a type of emission ‘sink’. The Kyoto Protocol of the UNFCCC, negotiated in 1997, sets limitations on emissions by industrialized countries but allows countries the option of substituting reduced emissions at home with reduced emissions in developing countries through the Clean Development Mechanism (CDM). The CDM allows for instigation of afforestation and reforestation projects as a method of reducing emissions, with only one project registered to date (United Nations Framework Convention on Climate Change, 2006). The CDM does not allow for reducing emissions through deforestation avoidance. Some argue that this omission could act as a perverse incentive to convert natural forests to plantations, accelerating existing trends in this direction. The same concerns that prevented avoided deforestation from being included in the CDM when the Kyoto Protocol was negotiated apply today: lack of detailed forest inventories, difficulties in setting an appropriate reference or baseline of deforestation, questions regarding permanence of emissions reductions and concerns regarding leakage from one avoided deforestation site to another area which may not have otherwise been deforested.

In April 2006, a group of scientists, practitioners and government representatives from both industrialized and tropical countries met in Austria to informally discuss these issues. The following represents the general recommendations that emerged from that meeting (Joanneum Research, 2006).

Participants agreed that the creation of a step-wise approach to avoid deforestation could serve a useful purpose. In the first stage, countries would be required to develop detailed inventories of standing forests as well as assessments of driving forces of deforestation and degradation in various locations. Capacity for monitoring and assessing future change as well as for measuring carbon capture in trees and soil would also be institutionalized. This stage would also allow the country to set its own reference or baseline for future deforestation. Support for such activities could come from financing by industrialized countries, perhaps through a global forest fund. Regardless of whether or not the country would eventually be able to exchange deforestation credits on any kind of a market, this type of monitoring, assessment and reporting capacity would be invaluable for informing all future policy regarding forest management and land-use change.

In the second stage, support could be given to create comprehensive National Forest Programmes and plans to use incentives and regulations to reduce deforestation levels. Such programmes could go beyond land-use planning, zoning and creation of protected areas to establishing specific measures aimed at affecting the behaviour of deforestation actors. Early gains could be made by targeting low-income small landholders. Other measures could include extension services to agriculturalists to train them in more intensive and more sustainable methods. Improving governance, including through a more locally driven participatory approach, could also be a component of this stage. As in the first stage, these activities would also be supported at least partly by industrialized countries.

It was agreed by participants that resources currently available through simple transfers in the form of Overseas Development Assistance (ODA) would not be able to reach the levels required to marshal significant change and some form of carbon credit trading scheme would be necessary. Using national level inventories of forests and carbon could provide a more appropriate measure of avoided deforestation, thus addressing concerns regarding permanence and leakage. The problem with national level, as opposed to project level, carbon trading relates to ensuring that the financial benefits garnered from avoided deforestation actually reach those actors responsible for the stewardship of those lands.

The ongoing discussions regarding how best to reverse the trends in deforestation within the context of the UN Forum on Forests and the accomplishment of the new international Global Objectives on Forests will contribute a great deal to reducing emissions from deforestation and forest degradation. From its outset, the primary objective of the UNFF has been to act as a normative process which provides an intergovernmental discussion of policies and practices needed to ensure 'the management, conservation, and sustainable development of all types of forests' (United Nations, 2000). In April 2007 governments completed negotiation of the Non-Legally Binding Instrument on All Types of Forests at the seventh session of the UNFF which will be passed through ECOSOC to the General Assembly to be adopted at its forthcoming session. The instrument sets a framework for accomplishing the Global Objectives on Forests, including reversing deforestation, and provides an internationally agreed conceptualization of what is meant by sustainable forest management. The negotiation of the instrument and its follow-up represents a continued and enhanced political will to address this issue at the global level. The Instrument places a strong emphasis on national actions as well as national policies and measures. Other issues of concern, including governance and law enforcement, monitoring, assessment and reporting, and assessment and means of implementation, including capacity building, financial resources and technology transfer, are also addressed (United Nations, 2007). The Forum also agreed to consider a possible financial mechanism to support implementation of the Instrument at its forthcoming session in 2009. The creation of a financial mechanism, either within the context of the UNFF and/or the UNFCCC will help transform political will into commitment and action.

Conclusions

It is most often the quest for income that drives deforestation and degradation, both by large-scale, wealthy extraction and agricultural interests as well as by small-scale commercial and subsistence farmers. The drivers and incentives for such action can vary substantially from region to region and, in fact, from one locale to another. Traditional policy approaches to rural development may succeed in raising rural incomes and creating more stable livelihoods, but may also inadvertently counter sustainable forest management goals. Targeting small-scale, low-income landholders and either raising their incomes through off-farm employment or providing income from sustainable forest management could provide significant gains in avoiding deforestation.

Avoiding deforestation could also contribute significantly to reducing the emission of greenhouse gases into the atmosphere, thus mitigating climate change. Attention to and support for such mitigation can have a significant impact on tropical forests. Such support will need to address lack of capacity in monitoring, reporting and assessment of forest degradation levels as well as land-use change, and will be needed to create national level programmes and incentives to encourage alternatives to forest conversion. In the end, the most important role any international financial instrument will play is to make sustainable forest management lucrative enough to support local social and economic development goals, thus ensuring the long-term health and vitality of people and forests.

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VI

Implications for Future Forestry and Related Environmental and Development Policy

This section presents the reports of four workshops. All four groups identified proposals for action to operate at the following levels:

- National and intergovernmental
- Private sector and civil society
- Voluntary and binding
- Market and non-market.

Mechanisms have been developed and are available for:

- Monitoring
- National forest programmes
- Standards, criteria and indicators
- Forest certification

The science is increasingly certain – indeed is '*unequivocal*' in the words of the IPCC Fourth Assessment Report. Concerns about climate change will continue to escalate in the international policy agenda. As we move forward new financial resources are likely to be mobilized for implementation of sustainable forest management. The knowledge and expertise exists to deliver, and action is required to develop practical actions to reduce the rate of deforestation, to restore forest areas where they have been lost or degraded and to manage the world's forests on a sustainable basis.

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24 Risks and Uncertainties

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Introduction

Seven questions were considered to have a major bearing on the risks and uncertainties associated with forests and climate change:

- What are the most likely effects of climate change on forest ecosystems?
- Which risks are the most important and how likely are they?
- What do we know and what more do we need to know?
- How should we respond to the perceived major risks?
- How good are our monitoring systems to inform management decisions?
- How resilient or flexible are forest ecosystems to changing environmental conditions?
- What is the likelihood of a catastrophic event?

The group thought that a 50-year time horizon was appropriate to considering these questions. Finally, consideration was given to responses to the risks as currently perceived.

Effects of Climate Change on Forest Ecosystems

Current and future increases in carbon dioxide (CO_2) and other greenhouse gases in the atmosphere will result in increased temperatures and changing patterns of precipitation. All of these will have both direct and indirect impacts on forest ecosystems. As noted elsewhere in this publication (Heimann, Chapter 3) deforestation is a major cause of climate change with a significant impact on remaining forest ecosystems.

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Climate change affects forests by changing the nature, scale and impact of a number of disturbance factors. While forest trees might be considered relatively static on a 50-year time scale, the pests and diseases to which they may be exposed are much more mobile and capable of moving with changing climate. Solomon and Freer-Smith (Chapter 19) quote examples from North America of damage from a wide range of pests and diseases where climate change is likely to be a significant contribution to vulnerability.

But forest ecosystems are more than just the trees. With changes in climate, new species will colonize leading to greater challenges to biodiversity, particularly as this may favour aggressive generalist species over those with a more limited niche.

Disturbance from abiotic or physical factors is also likely to change. Changing patterns of precipitation will result in forests becoming more vulnerable to drought and/or floods. Drier, hotter conditions also increase the risk of forest fires. Evidence that climate change is increasing the frequency and severity of storms is less clear. The impact of melting permafrost on the boreal forest ecosystem was considered to be a major risk and one where the likely impact was poorly understood but thought to be significant.

From the forester's perspective, the range of tree species which have commercial value may change either through natural processes or as a result of different species being planted. This could in turn adjust the balance of competitiveness between commercial forests in the tropics and the boreal regions. Some of the larger Scandinavian integrated forest companies are already switching the focus of their activities to tropical and semi-tropical plantations where shorter rotations have both an economic benefit and a reduced risk of vulnerability to the effects of climate change.

Finally, a number of human factors will influence how climate change affects the forest. As noted above, forest fires are likely to increase, with fires started by people, whether accidentally or deliberately, posing a greater risk in populated areas.

Importance and Likelihood

The importance of each of these factors depends on geographic location and on the extent of climate change. The group considered forest fires and melting permafrost to be particularly important because both have amplifying effects, leading to greater changes and impacts and challenging the resilience of the ecosystem. Drought, pests and diseases all lead to increased stress on trees which in turn increases their vulnerability to other damaging effects. The magnitude and severity of the impacts also then depends on climate change effects.

Knowledge Gaps

As well as developing an understanding of the drivers of climate change, there is a need to establish a baseline for measuring change. Work on determining the limiting factors for growth and how they interact should be used to focus effort. Those areas already known to be of importance are CO_2 fertilization, nutrients and water balance but there may be others currently less well understood. In particular, the role of soil processes is an area where both risks and uncertainties are high.

Where our current knowledge is derived from experiments, there is a need to develop ways of scaling up to consider impacts at the ecosystem scale. Similarly, the work on models needs to be evaluated with different disciplines coming together to seek ways of translating models to relate to the real world.

Responding to the Main Risks

While continued research will provide an evidence base to underpin both policy and practice, it should not prevent action now. At the strategic level, more needs to be done to ensure decision makers understand the links between forests and climate change. The existing knowledge of sustainable forest management gives a basis for developing effective responses and is well placed to offer workable solutions to minimize risk. However, knowledge transfer is a continuing challenge, particularly to ensure the development of locally appropriate systems. This extends into issues of governance, ownership, forest laws and land management addressed by Working Group 2 (Chapter 25). From a risk perspective, the less certain the governance, the greater the risk of other ameliorating measures being less effective.

In general, human impacts have a major role in determining the ability of forest ecosystems to respond to the effects of climate change. Population pressures, level of development and poverty all lead to greater risks. As an example, measures to create incentives to prevent deforestation depend on developing an understanding of the social and economic pressures which are driving land-use change so that effective alternatives can be offered.

Monitoring to Inform Management Decisions

Monitoring systems are of most value where they provide information which aids decision making. In an area of considerable uncertainty and limited resources, this presents a considerable challenge. Priorities can be better identified by influencing and improving the interface between scientists, policy makers and on the ground delivery.

On specific techniques, an integrated network of sensors may offer better cohesion and compatibility of information. The use of remote sensing also has potential as a cost-effective basis for monitoring and, given the high strategic importance of climate change, there may be scope for exploring military partnerships which allow access to state-of-the-art techniques. Monitoring greenhouse gas fluxes provides valuable information but is resource intensive. Identifying and concentrating on ‘hot spots’ may offer a means of directing resources for this and other monitoring efforts.

Resilience of Forest Ecosystems to Changing Environmental Conditions

Many of today's forests exist in environmental conditions significantly different to those which existed when the current trees were seedlings. Projections suggest climate change will continue. There is a need to understand the whole system to assess resilience. It has been suggested, for example, that soil microorganisms might adapt or evolve more quickly to changing environments. Looking at the tree species, some are fragile with limited genetic base or climatic tolerance while others may be more variable or tolerant. As the climate changes, barriers to migration, both physical and functional, may have considerable influence on resilience at geographical scales.

The risks associated with climate change challenge current policies and practices. For example, the preference for use of locally native material in areas of high biodiversity value may have to be tempered with the need for a wider genetic base to improve resilience. The tradition of foresters seeking to broaden the range of commercial species by use of provenances from similar latitudes may need to change to look, at least in Europe, to the use of more southerly origins.

Catastrophic Events

It is clear that there are huge uncertainties in climate change science and predicting the likelihood of catastrophic effects on forests is highly speculative. Current views are that catastrophic weather events, such as hurricanes, may or may not be increasing with climate change but their impact on forests under stress from other factors may be greater. The group also identified potential catastrophic events whereby certain ecosystems tolerate change up to a certain 'tipping point' beyond which catastrophic degradation ensues. The Hadley Centre has suggested that the Amazon Basin may be approaching this point (Cox *et al.*, 2000).

Responding to Risk

Returning to the topic of this workshop and the overarching question of risk, classical risk management theory (HM Treasury, 2004) suggests four possible responses to risk:

- Terminate.
- Transfer.
- Tolerate.
- Treat.

At the level of the forest owner or manager, all four responses may be possible, depending on individual circumstances. It may be possible to move out of forestry, to insure, to accept the losses if no action is taken or to intervene to reduce the risk to a level which is acceptable.

Taking a more global perspective across all forest ecosystems, as we only have one planet, this narrows the options to tolerate or treat. We need good monitoring systems to know when to stop tolerating and switch to treating and vice versa. Our 'risk appetite' should determine how bad we are prepared to let things become before intervening. This may be acceptable if the changes are part of a steady, predictable trend. However, if the idea of tipping points is valid, then this would favour a precautionary approach. Using the analogy of a canoeist on a river, there is a need to be aware that the waterfall is coming up in time to decide whether to go over it or to get out before the current is too strong.

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25 Governance and Climate Change

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Introduction

Focusing on the questions of governance and climate change, the discussion covered the different levels of governance, the practicalities of establishing robust and accountable systems and some of the risks of concentrating on a single issue.

Important themes throughout the discussion were communication and coordination, not only to ensure that decisions are made on the basis of good information but also to overcome differences in language and meanings that derive from a variety of international processes where each has its own particular vocabulary.

Coordination and Common Language

Internationally there are a number of relevant conventions and processes at both the global and regional level. Each has been negotiated separately with few mechanisms of coordination between them. Differences in vocabulary, where the same words or phrases mean different things in different processes, make definitions problematic.

This has wide implications:

- for coordination between international processes;
- for dialogue between countries and within countries;
- as a constraint on dialogue between different scientific and professional disciplines, for example legal, corporate, scientific, economic, political and diplomatic, that are engaged in the intellectual development of the climate change narrative.

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This difficulty in communication between professional groups highlights the even greater problem of communicating consistent and reliable messages to non-experts, including wider society but also stakeholder groups and their representatives whose interests will be affected by decisions relating to climate change.

Mitigating the effects of climate change will involve concerted efforts, involving changes of behaviour, across all parts of society in all countries. This will require simple messages, consistency and high levels of trust between scientists, politicians and wider society.

Simple answers rarely suit complex questions. We should avoid the temptation of presenting a complex socioeconomic problem as something to which there are known and easily applied solutions. We should not pretend that there is a neat, easily applied or quick solution to climate change. We are at the start of a new narrative that will require pilot schemes, learning by trial and error and good communication designed to address a wide range of audiences.

International Coordination

Simple 'outcomes' should be possible to negotiate. The immediate needs are to establish financial instrument with agreed rules and backed up by processes of monitoring and measurement as part of a global system of compliance. In the short term there is a significant amount of technical development required, in particular to establish baselines to underpin the international processes.

What problems did the group foresee?

- *Forgetting about sustainability.* Climate change falls within the wider narrative of sustainable development. There is a danger that climate change will simply be conflated with this broader theme of sustainability, so that 'sustainable development' is recast as a single-themed concern and becomes synonymous with climate change. In short, sustainable forest management (SFM) becomes a narrative about carbon farming and deforestation.
- *Carbon farming.* Related to this, the new imperative of climate change might lead countries and international organizations to engage in 'carbon farming' rather than SFM.
- *Perverse outcomes.* There is a very extensive international and country-level understanding of SFM, developed over a long period of time. Climate change brings new actors into this arena who do not share this common background. This is a welcome innovation since international progress on SFM has become very slow and complex. However, unless the lessons learned from SFM, especially the practical aspects of managing for sustainability, are retained in climate change then there is a strong possibility of perverse outcomes arising. An example might be the establishment of plantations to the detriment of native or local wildlife.
- *Reputational risk and political disengagement.* In addition to perverse outcomes there is an additional reputational risk stemming from the opportunities that climate change presents to make money through commercial engagement and

external funding. These provide incentives for actors to ‘spin’ climate change, perhaps making insupportable claims to maximize short-term financial gain. If this happens then the whole narrative will be discredited. The result will be that political action to encourage behavioural change in society will be much more difficult.

Sovereignty

The group was interested in the boundary between international and national responsibilities, and concluded that many of the activities that will be necessary to mitigate climate change fall to individual countries.

Just as the sociopolitical issue of deforestation is an issue that is in the domain of individual countries, so wider land use and land management are the responsibility of countries. The international community has no part to play in saying how individual countries should manage their land or deal with internal conflict arising from land use and land management.

Concerns over the aspects of climate change that relate to land use are focused on a relatively small number of countries. This means that there is a possibility of inappropriate, negative categorization of these countries through the adoption of inappropriate language. Climate change is just one of many issues the governments of these mostly developing countries have to deal with.

In respect of monitoring, targets and the development of market-based mechanisms, it is up to countries to decide how they will operate once the baseline constraints have been established.

Accountability

While national sovereignty applies to many of the actions for mitigating climate change, this does mean that consensus and negotiation will be required in respect of coordinating processes and market instruments. For example, carbon markets will require systems of monitoring, audit and reporting and also mechanisms to ensure delivery of contracted commitments with systems of redress for partial or failed delivery.

Where might ownership of these audit and compliance systems lie? Within the market, where bills of lading might indicate a suitable model, or with some supra-national body? The group also discussed how different approaches might impact on different types of player. For example, could the rules be applied in the same way to sovereign and corporate actors?

The group also asked whether the science was in place and sufficiently understood to underpin a rapid growth in market-based systems. Also, what procedures are required to account for *leakage*? Leakage arises when the net effect of the emissions reduction of one country is reduced because of consequential increased emissions from another, for example in the relocation of manufacturing.

Experience from the international sustainable forestry process is that simple things work, difficult things such as technology transfer do not.

Risks

In addition to the risks outlined above: perverse outcomes, commercial and trade risk and reputational risk, the group felt that the experience of the international forestry process pointed towards another important risk. This is the possibility of establishing an expensive and time-consuming process that delivers no outcomes at all.

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Response of the Forestry Sector

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Introduction

Globally, land-use changes associated with deforestation have contributed about 30% of the greenhouse gas emissions that are manifesting themselves as climate change and will continue to do so. Deforestation in the developed world allowed those countries to develop economically and, in the process, to contribute to the problem. Those same countries are insisting that the developing world preserves its forests to limit the effects of climate change that they set in train. In reality, only a concerted response involving the global forestry sector can deal with the problem before us; without this response, deforestation will continue unabated, contributing an estimated 18% of carbon dioxide (CO_2) and 30% of total greenhouse gas emissions. The requirement for a sectoral response is easy enough to identify – its nature and mechanism is more problematic and is the subject under discussion in this chapter.

The group considered options for a coordinated response from the forestry sector, including impediments to the implementation of the response. The discussion centred around a number of questions that, in turn, created the structure of this chapter, and can be summarized as:

- Are forestry policy and practice suitably integrated to accommodate the requirements of both climate change mitigation and adaptation?
- Has there been sufficient debate over conflicts between nature conservation/ biodiversity policy and the requirements for climate change adaptation at national level? In particular:
  - Will tree species migration into available habitat proceed at the rate required for survival without intervention?

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  - To what extent does stakeholder consultation stand in the way of implementing sound climate change adaptation measures?
- Is it possible to develop forest management responses that maximize the contribution of woodlands to climate change mitigation and optimize natural resource protection?
- How should the response of the forestry sector integrate with initiatives in other sectors, notably energy, building, agriculture, water and waste management?
- Is certification working effectively to ensure sustainable forest management and is enough being done to prevent illegal logging?
- Are 'environmental concerns' standing in the way of optimizing the response of the forestry sector to mitigate climate change?

Integration of Forestry Policy and Practice

The question is not whether forestry policy and practice are well integrated, globally, but whether sustainable forest management (SFM) can be practised locally within the constraints set by a range of other social, economic, environmental and political agendas. It is accepted that the sector knows how to manage forests sustainably, which forests to exploit and which not to. What is not valued is the wider contribution that forests make to environmental services and social well-being, resulting in their true value not being appreciated, either in monetary or policy terms.

Sustainable forest management was identified as key to the development of successful adaptation and mitigation measures. However, the interpretation of 'sustainable' and 'sustainability' varies between regions and defines the response that the forestry sector can make. The most important issue is whether SFM should encompass the maintenance and/or enhancement of productivity, as some environmental non-government organizations (NGOs) consider these aims to be unsustainable. The response of the sector to this argument is that if its contribution is to be maximized, timber and biomass production must be retained at a global level, with the proviso that SFM considers all three of the pillars of sustainable development – environmental, social and economic.

It was concluded that the integration between policy and practice is dependent on the definition of sustainability at both a national and local level. Critical issues are whether the definition is restricted to the forest or is applied to the wider landscape, and whether forestry policy can be developed without undue influence from other policy drivers which may be at odds with a holistic expression of sustainable forest management. These externalities are further explored in the sections of this chapter which deal with optimizing the sector's response to adaptation and mitigation.

At another level, conflicts exist between forestry and climate change policy, with different emphases expressed in different fora. For example, climate change policy expressed through the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol focus on afforestation and deforestation (although reforestation is also considered, to an extent). In contrast, international forestry policy (United Nations Forestry Forum (UNFF) and predecessors) concentrate on deforestation. The area that seems to fall between stools is reforestation and landscape restoration, an area that the sector understands well. More importantly, reforestation and landscape restoration could make significant contributions to reducing deforestation in the longer term. This is because only 7% of forests, globally, are required to provide the current demand for timber, so that sustainably managed plantation forests on these degraded and deforested lands could sustain this level of future demand, relieving the pressure on virgin forests and other woodlands of high conservation value.

How ever great the synergies between policy and practice at national or regional level and whatever the sector's understanding of the issues involved, it is clear that global forestry policy and practice are not well integrated. Improved integration must be the goal of a concerted response from the forestry sector.

Adaptation

Adaptation to climate change can be defined in two principal ways:

1. Maximizing the environmental services of woodlands to counter the predicted impacts of climate change.
2. Making woodlands more resilient to the impacts of climate change.

The environmental services provided by forests range from the protection of water supplies, flood alleviation, maintenance of soil quality and long-term fertility, supply of non-timber forest products and woodfuel through to natural habitats and nature conservation. These services are rarely reflected in payments made to forest owners, either private or public, but may represent a source of revenue that could reverse deforestation and help to reduce global CO_2 emissions. Through the recognition of these services, afforestation schemes and woodland creation programmes might also contribute to climate change mitigation through sequestration as well as providing a renewable resource of timber and wood-fibre for future generations. Although there is almost universal acceptance that such a mechanism would help to break the log-jam in international negotiations to reduce deforestation, there are arguments over how such schemes would be administered, over approaches to financial incentivization and over the valuation of such services. Furthermore, claims have been made in the past that exaggerate the value of these environmental services, or claim benefits when none exist. However, the approach does show promise and should be considered alongside the carbon benefits of maintaining existing and planting new forests. Indeed, a market in these services is developing in isolated cases, such that payments are being made for water protection services in New York state and EU funding is directed to tree planting in southern Europe to mitigate soil erosion.

Making forests more resilient to climate change can be undertaken in a range of ways, incorporating both changes to their management and planning and to their composition. If the future climate of a region was known with any certainty, the global genetic resource available to us would ensure that resilient forest ecosystems could be established in almost all the terrestrial environment that currently support forests. However, in so doing, many current 'rules' of genetic conservation and biodiversity policy would be broken. The interpretation of these rules, including the Convention on Biological Diversity and the EU Habitats Directive, varies from country to country and from region to region. For example, in Iceland, all species present prior to 1948 are considered suitable for planting in an afforestation programme which aims to create ‘climate-proofed’ woodland. This contrasts with the position in the UK, where only those species which the pollen record shows as being present prior to the breakage of the land bridge 5000 years ago are considered native, and only in those regions to which they had advanced. This results in policies that are incongruous at first sight, such as grant-aid being paid for the eradication of beech in northwest England, a likely receptor region should the species fail in southeast England, as climate change predictions suggest.

Optimizing Climate Change Mitigation and Natural Resource Protection

If forests are managed according to the principles of sustainable forest management, then optimizing climate change mitigation is fully consistent with the objective of managing them for sustainable growth. Natural resource protection, when SFM is applied at the landscape level, would fall within this definition. However, if climate change mitigation is viewed in isolation, then over-exploitation of the forest resource is a distinct possibility.

A specific area where the sector is responding to climate change in isolation, is tree planting for carbon offsetting. In many cases, requirements are for native species to be planted and retained in perpetuity with no mention of management intervention. Questions have to be raised over whether restricting species choice to those currently or historically native to the region is sustainable in the light of climate change predictions and, also whether ‘putting a fence’ around the woodland and treating it as a carbon reserve is truly maximizing the response to climate change. Although offsetting projects have the potential to make a significant contribution to both mitigation and adaptation, they are often poorly explained and publicized, with claims over their contribution exaggerated. In particular, a number of the approaches to carbon accounting have led to significant resistance from a range of environmental NGOs – notably carbon ‘credits’ being awarded in advance of the carbon being sequestered. Tree-planting projects of this kind do have the opportunity to play a part in combating and adapting to climate change, but carbon sequestration is but one benefit. Indeed, the value of environmental services together with timber and bioenergy production are, potentially, as great, if not greater, and carbon sequestration should therefore be seen as a co-benefit, rather than the sole benefit of woodland creation. An integrated sectoral response of this nature would therefore have two effects:

1. Minimizing resistance against such schemes.
2. Maximizing the sector’s contribution.

A second specific area, relating to natural resource protection and to the role that forests can play in mitigation, is soil carbon management and climate change.

Evidence has recently been presented that soil carbon losses are significant, largely as a result of management practices which do not consider the impacts of climate change. There is also a great deal of uncertainty, with responses likely to vary between biomes and with approaches to forest management. However, there are a number of guiding principles:

- Forest soils accumulate carbon relative to more intensive (agricultural) land uses.
- Globally, forest soils contain more carbon than is stored in vegetation and the preservation of those stocks is therefore a priority.
- The application of fertilizers can enhance production of above-ground biomass and, as a consequence, soil carbon stocks; however, the consequent enhanced emissions of nitrous oxide need to be considered using life cycle analysis.
- Soil carbon stocks are significantly influenced by litter inputs – the management of brash and harvesting residues should therefore consider soil carbon, particularly where removal for bioenergy production is advocated.
- The impact of both climate change and forest management will be highly variable and site dependent, particularly when the responses of temperate and tropical forests are compared.

The points made above indicate that there is large uncertainty and, therefore, we do not know every last detail of how to preserve or enhance soil carbon stocks. However, far more is known about soil carbon management for forest soils than for many other sectors. We can never know enough to be certain of the impacts of every management action, but need to use the available information to guide best practice; uncertainty can be no apology for inactivity.

In summary, the sector should not, and has no need to, focus solely on mitigating climate change, but should integrate this response with a contribution to wider aspects of sustainable land management.

Integration with Other Sectors

It is clear from preceding sections that integration across all sectors associated with land management is necessary to optimize the forestry sector's response to climate change. However, before that can happen, the forestry sector needs to clarify its position and prioritize responses to climate change. The contribution that is often overlooked is the role of timber and wood products in indirect fossil fuel substitution or product displacement. This is, in part, a result of a lack of detailed analysis (whole life cycle) of the forestry woodchain. In the absence of a universally accepted analytical methodology, the evidence base for transferring what is generally believed to a policy response is unlikely to proceed. Moreover, there is even greater uncertainty associated with the economic benefits, opportunity costs and replacement costs when different land uses are considered. In part, such a comprehensive economic analysis stands in the way of the environmental services that forests provide being fully appreciated and reflected in payments made to the sector. Without these services being acknowledged, it is unlikely that full integration with other sectors can be achieved.

Certification

Certification is working to some extent and has been particularly effective in awareness raising of the issues of deforestation and sustainable forest management. The main problem is that it is not working throughout the world and, therefore, there is a far from level playing field. There are also some concerns over the effectiveness of certification, particularly in ensuring the maintenance of environmental standards. While the second problem is difficult to overcome, a requirement of certification for timber market entry would create a level playing field and ensure that certification, and therefore the employment of sustainable forest management, was universal. This could only be achieved through voluntary/self-regulation, requiring closer collaboration between producer and end-user parts of the forest-based sector. If certification is accepted as a minimum requirement for market entry, traceability and chain of custody will become higher profile issues than at present. Better systems therefore need to be put in place to give confidence in the concept and application of certification and reduce pressures for deforestation.

Conflicts between 'Environmental Concerns' and the Response of the Forestry Sector to Climate Change

At present the sector is not responding strategically to climate change. Some environmental bodies are resisting change that would contribute to both climate change mitigation and adaptation, while current rates of deforestation clearly demonstrate that the sector is not addressing how to reduce the contribution of the forestry sector to climate change. Drivers for deforestation are largely economic and social/societal, and therefore outside the scope of this discussion. The resistance of some environmental bodies to change is the result of a number of arguments:

- Although there is largely (scientific) consensus that climate change is a reality, there is uncertainty in its rate and magnitude. More importantly, while predictions of temperature change are generally seen as robust, far less certainty is associated with predictions of changes to rainfall patterns, which are likely to have an overriding impact on species ranges, survival and growth rates. As a result of these uncertainties, there is little consensus on how to respond, particularly where significant intervention or alterations to existing biodiversity or conservation policies are required.
- Biodiversity and conservation policy have achieved much by protecting existing definitions of ecosystems and natural community structure. There is therefore an underlying sense of preservation rather than conservation.
- Some environmental bodies believe that nature is resilient to change, and that significant changes have occurred in the past. There is therefore a view that climate change adaptation should be left to natural evolutionary and migratory processes.
- Conservation and biodiversity policies are generally focused on protecting existing species/biodiversity, rather than on securing functional ecosystems

in the future. These policies promote existing species on the basis of nativeness, rather than on their potential to provide ecosystem services in the climate of the future – or on the basis of adaptedness or adaptability. The nature of this barrier is illustrated by the requirement of most 'offsetting schemes' to use native species, often of local origin.

- With respect to mitigation, the largest contribution that the forestry sector can make (apart from reducing rates of deforestation) is to fully utilize the available resource from sustainably managed woodlands to substitute, either directly or indirectly, for fossil fuels. Some environmental bodies argue against any type of management intervention and promote the reversion of increasing areas to non-intervention or protection forests. Although this may be an appropriate action in many locations, it has the potential to significantly limit the contribution of the sector at a global level.
- Management activities aimed at maximizing climate change mitigation may draw environmental criticism; examples include the conflict between woodfuel utilization versus retention of deadwood for enhancement of biodiversity and intervention to enhance timber quality/production versus 'natural' woodland structure.

The arguments outlined are by no means exhaustive but represent a significant barrier to realising a maximum contribution from the sector. However, these issues can be viewed from another angle, namely that climate change is the vehicle for optimizing the wider environmental and social services that the forestry sector can provide, with these services not restricted to direct climate change adaptation/mitigation, but across all three pillars of sustainable development.

Conclusions

It is clear that the forestry sector, as a whole, is not making the contribution to climate change mitigation that it is capable of doing – if it was, deforestation would not continue to be responsible for 18% of global CO_2 emissions. At the same time, the sector's response to adaptation is limited which, for a sector that has planning horizons of upward of 50 years and needs to be one of the first to respond, cannot be seen as acceptable. In both cases, the principal reasons behind the absence of concerted and coherent actions are the range of conflicting issues and policies, and the lack of articulation from local to national and global fora. To accommodate these conflicting interests, the forestry sector needs to present an unanimous and coherent argument that action is required. In turn, for this outcome, the wider contribution of forests to the three pillars of sustainability need to be accepted and valued – presumably in monetary terms. However, this logical process is unlikely to be realized if the international negotiating mechanisms in the forestry sector remain as impotent as has been apparent in recent years, and if conflicts continue between climate change and forestry negotiating processes.

The barriers identified above may seem to be intractable, but they can be surmounted if the sector returns to, and concentrates on, the central tenet of a successful sector – sustainable forest management. If it is accepted that the concept of forest management extends beyond the forest boundary and that forestry is a part of sustainable landscape management, then both the focus for the response and the true value of the sector in terms of environmental services will follow. As a result, adaptation measures will be seen as essential for the sustainable future of the sector, utilization of forest resources within a framework of environmental sustainability will be optimized, payments for environmental services provided by forests will be received and, as a consequence, the principal drivers for deforestation will be negated. The corollary is that, without a coherent response from the sector focusing on sustainable forest management, the potential for addressing each of the individual aspects – deforestation, adaptation and mitigation – is diminished.

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Commercial and Project-based Responses and Associated Research Initiatives in the Forest Sector

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Based on workshop discussions with Jeffery Burley, Denis Loustau, Jim Lynch, Gregg Marland, Robert Matthews

Introduction

The workshop was held to discuss and propose conclusions and recommendations regarding strategies for the forestry sector to facilitate real greenhouse gas reductions or offsets against fossil fuel use. To initiate the discussion, a range of questions was put to the group relating to the ability of commercial forestry or government projects to contribute to this effort. The following abbreviated list of questions illustrates the issues raised:

- Is it easy or difficult to quantify and verify the benefits delivered by forest-based climate change mitigation projects and business ventures?
- Carbon incentive or credit schemes may contain unintended loopholes or consequences. How do we avoid them?
- How should we assess the benefits of increased carbon storage in forest ecosystems versus the benefits of reduced fossil emissions from the use of harvested biomass for the substitution of fossil-emission intensive products and energy?
- How should the benefits of intensive forest management for climate change mitigation be weighed against other benefits from forest management, e.g. water supply quantity and quality, biodiversity, albedo (the proportion of incident radiation reflected), social and cultural attributes, and aesthetics?

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- Given that viable mitigation and adaptation systems and schemes must be formulated, are there gaps in knowledge or understanding that need to be addressed by new research?
- What specific research must be completed to facilitate unbiased and tractable selection and application of carbon mitigation schemes?

Within the limited discussion time available the following were discussed or mentioned:

1. Strategies to drive the use of biofuels for mitigation of greenhouse gas releases.
2. The need to reduce deforestation and forest degradation.
3. The importance of planning for adaptation in response to expected climatic change.
4. The benefit of a comprehensive analysis of the contribution of forestry sector components to mitigation.
5. Methods to motivate private and public activities that yield efficient and climate-friendly outcomes.
6. The desire to maintain a viable research programme on climatic change impacts for application to risk analyses and cost–benefit calculations in support of forest management and policy decisions.

Biofuels for Mitigation

Increased biofuel production and use to mitigate greenhouse gas emissions and offset the use of fossil fuels were recognized as an obvious strategy for the forestry sector to pursue. Methods and projects need to be developed on commercial scales under economically viable conditions for them to make serious contributions globally. Two steps towards this end were to recognize the factors that might currently be impeding the development of such projects and to propose incentives that governments might institute to foster biofuels programmes. To avoid inefficient programmes and minimize the initiation of those that might result in unintended pitfalls, it was concluded that projects or plans should be fully evaluated prior to broad application. Desirable characteristics for any large-scale biofuels initiative would include analysis of impacts at regional and global scales, and the use of a comprehensive ‘systems’ approach to avoid gains in one area at the expense of losses elsewhere (e.g. Marland and Schlamadinger, 1995; Sonne, 2006). Projects should be carefully evaluated to avoid unintended pitfalls particularly in relation to their overall energetic balances as well as their economics. For example, long-distance shipping of low-density biofuels to allow their use for energy production will result in reduced greenhouse gas benefits if the amount of fossil-based carbon fuels used for transportation are large in comparison to the fossil fuel displacement gained at the point of end use.

It was expected that any successful biofuels projects would demand a simple approach to be widely adopted by society, but at the same time would need to be supported by a thorough understanding of the complexity of issues related to the energy and cost efficiencies involved and the wider context in which projects operate. The group suggested that biofuels projects intended for the mitigation of fossil carbon emissions might tolerate sub-optimal carbon savings during a ramping up period to get projects under way. Any system would, however, need to provide true long-term emissions reductions or offsets if it were to be adopted for sustained application.

The group concluded that much of the information needed to support the use of biofuels may already be available from previous research and may even have been translated to specific management concepts (Sampson *et al*., 1993; Bloomfield and Pearson, 2000; Tuskan and Walsh, 2001). A substantial spectrum of commercial opportunities exists, but commercialization mechanisms, incentives and education regarding the motivation for biofuels programmes are still lacking. The requirement for business to recognize social and ethical issues will be paramount (Burley *et al*., Chapter 5). Optimum management practices should be described and assessed by the research community through a technology transfer initiative to educate the public on carbon management activities applicable to the forestry sector.

Reduction of Deforestation and Forest Degradation

Because deforestation and forest degradation are a major source of greenhouse gases to the atmosphere (Dixon *et al*., 1994) and are expected to continue to be so (Schlamandinger and Johns, Chapter 10), much emphasis is placed on projects and plans to avoid future forest losses from deforestation and degradation. Conservation (ongoing protection) and sustainable management of forests are the two pathways available to ensure that carbon stocks are protected. In a carbon context, the goal of conservation is to maintain carbon stocks and the goal of sustainable management is to allow harvests that temporarily reduce carbon stocks to provide harvested biomass for the displacement of fossil fuel use.

To encourage private sector or government investment in the reduction of deforestation through management, protection and conservation, particularly in developing countries, approaches for translating such activities to monetary or carbon values are needed. In addition, accounting methods must be developed to handle risks associated with natural disturbances (e.g. fire, disease, pests and wind) that will periodically perturb and release carbon stored in natural ecosystems. The group also concluded that value systems associated with forest protection should not be limited to carbon sequestration potential alone but should recognize the importance and value of forests as sources of biodiversity, water supplies, social, cultural and aesthetic attributes, and recreation.

A global strategy for the minimization of deforestation and forest degradation should identify those forests most useful or suited as long-term reservoirs of carbon. This will involve recognizing regional variations in the potential of forest ecosystems in terms of suitability of wood production for specific end-uses and potential vulnerability to disturbance, as well as national and regional circumstances that lead to deforestation and degradation. It may also be possible to identify ecological criteria to guide prioritization of regions and forest types in a global programme aimed at reducing deforestation and degradation (e.g. productivity and ability to regenerate after disturbance). Socio-economic, institutional and cultural issues will also need to be considered. Simply on the basis of the extent of land cover which they represent, it is logical to consider the protection or conservation of tropical forests in Africa, Asia and the Americas. Research might also be undertaken to determine if local woodlands and small land areas located in populated mid-latitude regions have a role to play in the global stabilization of greenhouse gas emissions to the atmosphere. Strategies for long-term protection of forest carbon stocks will need to account for the ownership characteristics of the lands in question since management approaches for private- versus government-owned lands are likely to demand different strategies. The impact of forests on other climate factors, such as albedo and latent energy transfers, will need to be considered.

The group felt that managed forest systems could play a significant dual role in maintaining or enhancing carbon stocks above and below ground while allowing for sustained use of harvested forest biomass for wood products and biofuels. As when determining strategies for forest protection, it was pointed out that a measure of the productive potential of a given forest might provide a key metric for deciding which forests should be preserved as ‘carbon reserves’ and which might be used for sustainable management. The higher the productive potential, the quicker the forest’s ability to replenish carbon stocks removed during harvest (see Matthews *et al.*, Chapter 12).

Key research needs associated with the crediting and compensation of activities aimed at reducing deforestation and degradation revolve around the ability to define appropriate baselines against which to judge the effectiveness of such activities. The research and policy communities need to evaluate baselines that are either static or dynamic over time. Future climatic conditions may lead to unforeseen biological responses that could necessitate the use of dynamic baselines in the future. The group emphasized the importance of developing incentives and associated baselines that did not lead to surprises for those engaged in emissions trading. It was recognized that instability in emissions trading markets could lead to a loss of confidence by investors, representing a potential threat to sustained efforts to mitigate climate change.

The valuation of projects to minimize deforestation, enhance afforestation or reduce forest degradation, or manage stands to sustain forest carbon and reduce emissions through the use of forest biomass requires reliable and credible assessments of forest carbon stocks. Appropriate methods are readily available to evaluate forest carbon stocks at specific locations within established forest inventory networks (Clark *et al.*, 2001; Brown, 2002; Holmgren, Chapter 20). However, the group considered that more concerted efforts were needed to translate these methods into practical, operational manuals that individuals, companies and institutions could apply without recourse to detailed scientific expertise. The group also recognized the need to look for improvements in the ability of remote sensing methods to measure forest carbon stocks (at least above ground) at global scales. Downward looking light detection and ranging techniques (LiDAR) to evaluate forest wood volume holds promise as such a method (Patenaude *et al.*, 2004; Jensen *et al.*, 2006). Remote sensing methods applicable at global scales would provide a routine (albeit coarse resolution) approach for monitoring compliance with international reporting of forest carbon stocks. Together with periodic ground truth measurements for above- and below-ground carbon stocks, the combined data would provide the basis for an approach to monitor leakage and compliance. An important question concerns the required resolution of carbon stock estimates needed to ensure compliance and effective monitoring of policy measures or commercial schemes, for example when deciding to collect stand-by-stand assessments or rely on simple default values for carbon stocks in different forest types (Kirschbaum *et al.*, 2001).

Plans for Adaptation

While not discussed in detail, given the time available, the group recognized the need for research within the forestry sector to address plans for adaptation to projected rapid climatic change. Proactive plans for optimizing the diversity of species within managed landscapes, to enhance future productive potential, and to retain carbon stocks in the face of anticipated increases in pest and disease problems were mentioned. Genetics research and tree breeding practice have major roles in maintaining adaptability within populations while enhancing productivity.

Analysis of Forestry Sector Mitigation Contributions

A recommendation was made that members of the forestry community should undertake a detailed analysis of how forestry-based mitigation efforts could contribute to the stabilization of greenhouse gases in the atmosphere. One such activity might follow the example of Pacala and Socolow (2004) who evaluated ‘stabilization wedges’ for the quantitative and comparative analysis of a wide range of technological fixes for replacing or limiting carbon emission rates in the future. Their analysis included the substitution of biomass for fossil fuels and a combined assessment of how reduced deforestation, afforestation and forest plantations could contribute as well. The group’s discussion suggested that a similar evaluation focused on forest sector responses would represent a potent analysis and tool with which decision makers could plan a complete portfolio of methods for reducing carbon sources and enhancing carbon sinks.

Impacts for Research

Environmental problems associated with climatic change will be unprecedented and the costs for mitigation and adaptation are likely to be significant (Stern, 2006). Therefore, it is important that the scientific community continues to reduce uncertainties associated with anticipated climatic change impacts to provide the best available information against which mitigation and adaptation choices can be made by society. The research community needs to proceed beyond a simple enumeration of possible outcomes from climatic changes (Intergovernmental Panel on Climate Change, 2001) to more specific projections for the following:

- The atmospheric greenhouse gas concentrations that would lead to specific forestry sector impacts defined to be unacceptable by society.
- The future timing of unacceptable outcomes.
- The ranking of unacceptable consequences to prioritize research, mitigation and adaptation initiatives.

Observations and experimental manipulations alone will not be able to generate sufficient data for forest management and policy makers' needs. The tools for evaluating future climatic change responses at regional to global scales are dependent on the development of mechanistic models that can be integrated through time and space for prognostic estimates of future ecosystem response. New observations, experiments and enhanced modelling capabilities for forest sector responses are needed to prepare risk analyses and cost–benefit calculations in support of forest management and policy decisions. Actions to mitigate climate change will, however, still need to be initiated and operated in the context of considerable uncertainty. The establishment of research priorities should consider local and global analyses of a given measure in terms of the uncertainty of the predicted outcome as part of managing risk and potentially developing no-regrets strategies. A clear distinction needs to be made between the high level of complexity required in analyses of long-term impacts of climatic change, adaptation strategies and their interaction versus the straightforward approaches needed to evaluate near-term mitigation options.

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Forests and Climate Change: Conclusions and the Way Forward

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Introduction

Trees and forests play a crucial role in regulating our climate. Trees remove carbon dioxide (CO_2) from the atmosphere through photosynthesis as they grow and store it as carbon in carbohydrates, lignin and cellulose. The carbon is stored in the biomass – the trunks, branches, foliage, roots, etc – and in organic carbon in the soil. In young forests carbon is sequestered at high rates, while in mature forests sequestration slows, respiration and decomposition increase and the carbon balance more or less reaches a steady state. Forests therefore act as carbon storehouses. When new forests are created, they sequester carbon and become a sink of carbon. But when existing forests are cleared, the carbon is released and acts as a source of greenhouse gases.

The amount of carbon stored in forest ecosystems including soils is around 1200 gigatonnes (Gt) of carbon, equivalent to some 4500 Gt of CO_2. This is more than that contained in all the world's remaining oil stocks. It is also more than the total amount of carbon in the atmosphere.

Forests can therefore be used as a tool in developing solutions to the problem of climate change. Planting new forests, restoring degraded forests and managing existing forests using sustainable management practices can all be used as ways to increase carbon sequestration. However, forests are being cleared and degraded, and at an alarming rate. Some 13 million hectares (ha) of forest are lost each year and this deforestation is responsible for nearly 20% of all the global emissions of greenhouse gases.

The World's Forests

The world's forests cover just under 4 billion ha – 30% of the total land area. They range from boreal and temperate forests to arid woodlands and tropical

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moist forests, and extend from undisturbed primary forests to forests managed intensively for a wide variety of purposes. The distribution of forests around the world is uneven. Ten countries – the Russian Federation, Brazil, Canada, USA, China, Australia, Democratic Republic of Congo, Indonesia, Peru and India – account for two-thirds of the total forest area, and more than half is in just five countries – the Russian Federation, Brazil, Canada, USA and China.

Historical Changes

Around 8000 years ago, 50% of the world's land surface was covered by forest, compared with only 30% today. When forests are cleared for agricultural or other uses, it is common for a large proportion of the above-ground biomass to be burned, rapidly releasing carbon into the atmosphere. Cultivation further increases the release of carbon from the soil. Deforestation and land clearance in some industrialized countries in Europe and in North America prior to the 20th century caused significant emissions of CO_2. Today, the situation has been reversed and forests in these countries are now absorbing CO_2 through natural regrowth and enhanced vegetation growth. Estimates for 1875 show that Europe, North America and the former Soviet Union contributed most of the global emissions from deforestation. Today, most global emissions from deforestation are from the tropics. Since 1850, deforestation is estimated to have resulted in a net release of some 150 Gt of carbon. Of this, about 40% was released during the first half of the 20th century from mid to high latitudes, and about 60% from the tropics, mainly since the 1950s.

Current trends

The total forest area is continuing to fall, though the net rate of loss is falling. Deforestation – mainly driven by the conversion of forests to agricultural land (see Plate 12a–e) – results in the loss of some 13 million ha of forest each year. At the same time, forest planting, restoration and the natural expansion of forests have significantly reduced the net loss of forest area. The change in forest area in 2000–2005 is estimated at a net loss of 7.3 million ha a year. However, this is down from 8.9 million ha a year in the period 1990–2000.

The pattern of deforestation across countries and regions is highly variable, with a majority coming from tropical countries, although the forces driving deforestation vary around the world. South America suffered the largest net loss of forests from 2000 to 2005 – about 4.3 million ha a year – followed by Africa, which lost 4.0 million ha a year. The five countries with the largest net losses in 2000–2005 were Brazil, Indonesia, Sudan, Myanmar and Zambia. Asia, which had a net loss of some 800 000 ha a year in the 1990s, reported a net gain of 1 million ha a year from 2000 to 2005, primarily as a result of large-scale afforestation reported by China. The forest area in Europe continued to expand, although at a slower rate than in the 1990s.

Deforestation does not only exacerbate climate change. It impacts on the way of life of those dependent on the forests, and the products and services that forests provide. These include biodiversity (70% of all the world's biodiversity is found in forests), flood protection and erosion control, and the supply of timber and non-timber products, such as natural medicines.

Protecting, restoring and managing the world's forests on a sustainable basis will not only help to mitigate climate change but also deliver the full range of goods and services that forests are able to provide.

A continued decline in forest cover across the world is not inevitable. There is considerable expansion in forest area in many parts of the world through large-scale afforestation programmes – for example in parts of Europe and China.

Forests and Carbon

Since the beginning of the industrial revolution, atmospheric concentrations of CO_2 have risen by 35%. A large proportion of this increase is from the burning of fossil fuels and from deforestation. In order of importance, it has been estimated that the largest contributors to global emissions are electricity and heat (25%), land-use change, principally deforestation (18%), transport (14%) and agriculture (13%). Emissions from deforestation are therefore greater than the whole of the transport sector. The IPCC estimates that during the 1990s, global carbon emissions from deforestation averaged some 1.6 GtC a year ± 0.8 GtC. While the figure of 18% is towards the top end of the range that IPCC has identified for deforestation, it does not include emissions from peat fires linked to deforestation in South-east Asia. By any measure, deforestation is a very significant contributor to global emissions of greenhouse gases.

Forests can contribute to climate change mitigation in three main ways: conservation, sequestration and substitution.

Conservation

Conserving existing forests protects the carbon already locked up in them. The key measures are to reduce the rate and amount of deforestation and to reduce the rate of forest degradation. Measures for conserving forest carbon stocks should also consider the soil carbon store.

Sequestration

Increasing the area of forests by afforestation (establishing new forests) or reforestation (re-establishing former forests) on marginal agricultural land and on abandoned land can increase carbon stocks by removing CO_2 from the atmosphere. This can be achieved in a number of ways, including approaches that aim not only to increase the carbon stocks of forests, but also to contribute positively to local livelihoods and to protect the range of ecosystem services that forests can provide.

The sustainable management of existing forests can also enhance carbon uptake and therefore increase sequestration. Increasing the rotation length and managing harvesting cycles are examples of practices that can increase carbon uptake.

Substitution

Substituting fossil fuels and energy intensive materials, such as concrete, steel and plastics, by wood products can also be used as a means of reducing overall CO_2 emissions.

Using woodfuel from sustainably managed forests can supply bioenergy without significant net emissions. In many developing countries, wood energy – usually in the form of fuelwood or charcoal – is the most important source of energy for 2 billion people, mostly the poor who lack access to modern energy services. In developed countries, there is great interest in developing biofuels for transportation as well as biomass for heat and electricity. The commitment of governments worldwide to fossil fuel alternatives means that the use of biomass for electricity generation is forecast to triple between now and 2030. There are also opportunities for smaller-scale heating schemes in areas currently dependent on fossil fuel heating such as oil and coal.

Wood products generally have lower carbon emissions associated with their production compared with other materials for which they can be substituted, such as concrete, steel and plastics. Wood products from sustainably managed forests are a natural, renewable and sustainable resource. The carbon they contain remains stored for the duration of their lifetime, until they decay or are burnt. As such, a global increase in the industrial use of wood products would increase the amount of carbon stored. The ways in which wood products can be managed to increase carbon stocks include:

- Increasing the useful life of these products: the longer the wood product is used, the longer the period of time the carbon is stored within it.
- Increasing product recycling: the storage is increased the more times the product is used and recycled.
- Capturing the product's energy at the end of its life cycle (notably for heat and electricity).
- Shifting the product mix to a greater proportion of wood products: substituting building materials such as concrete and steel by sawn timber can result in significant savings of greenhouse gas emissions. Replacing 1 m^3 of concrete or red brick with the same volume of sawn timber can save around 1 t of carbon.

The Global Policy Dialogue

Addressing global climate change is a paramount challenge for the 21st century. Industrialization and economic development have resulted in a sharp rise in emissions of CO_2 and other greenhouse gases. Forests, and how they are managed, play an important role in the global greenhouse gas budget. The potential implications of this started to be recognized in the late 1980s in the discussions leading to the global environmental summit in 1992 in Rio de Janeiro. Ever since, the role of forests has featured in the international climate change negotiations.

The international community has negotiated the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol with the aim of confronting the trend of rising greenhouse gas emissions in the atmosphere and ultimately reversing it. Despite the significance of the scale of emissions from deforestation, the use made of forestry activities is limited. Most importantly, neither the UNFCCC nor the Kyoto Protocol includes a mechanism to reduce emissions from deforestation.

Article 3.3 of the Kyoto Protocol obliges developed countries – but not developing countries – to account for emissions from deforestation as part of their efforts to reduce emissions. Reducing emissions from deforestation was considered as an eligible activity under the Clean Development Mechanism (CDM), but the proposals proved controversial for two main reasons. First, because of the risk that individual projects would displace the deforestation elsewhere and, second, because of the potential scale of allowances that could be generated, given the emission reductions already agreed and the perceived need to focus effort on reducing emissions from, primarily, the use of fossil fuels.

There were also concerns about accounting rules and the issue of the permanence of carbon storage in forestry activities; carbon stored in forests is only of benefit as long as it remains sequestered – if the forest is removed, the stored carbon is released and the benefit is reversed. Unlike emission reductions in other sectors, most forestry activities are, by their very nature, 'non-permanent'. However, a solution for potential non-permanence was found for afforestation and reforestation activities under the CDM, and sustainable forestry activities which result in either direct or indirect fossil fuel substitution do constitute a permanent measure.

In the end, the issue of deforestation in developing countries was left out of the Kyoto Protocol. Although deforestation and forest management are counted for developed countries, activities eligible for the CDM were confined to afforestation and reforestation, and there are limits on the amount that forestry activities can contribute to emissions targets in general.

Nevertheless, interest in combating forest loss in developing countries has not gone away within the UNFCCC, and it is also recognized that the causes of deforestation, and the benefits from reducing it, go far beyond the simple issue of forestry and carbon. It is common ground that any mechanism to reduce emissions from deforestation that is linked to emissions trading would have to be for the second and subsequent commitment periods (therefore beyond 2012). However, this does not rule out the possibility of voluntary mechanisms being introduced before then. Indeed, despite uncertainties about the outcomes, a range of proposals for tackling this problem are now coming forward. These include proposals from governments, the private sector and civil society, including non-government organizations. They include using debt forgiveness in return for forest protection, using insurance markets to protect forests, using international finance to back national action and developing carbon markets to provide incentives. To work, any proposal must be acceptable to the developing countries on whose sovereign territory the forests lie.

Since 2000, the United Nations Forum on Forests (UNFF) has been working to provide a framework to deliver sustainable forest management around the world. Among other things, the Forum provides a focus for countries to compare experiences with their National Forest Programmes, and demonstrate progress in the sustainable management of their forests. The work of the UNFF is supported by the Collaborative Partnership on Forests (CPF), made up of the major international organizations and bodies involved in forests, including the UNFCCC. Through the work of the CPF and coordination and cooperation of its members, there is potential to make progress in developing effective mechanisms to implement sustainable forest management on the ground and to monitor progress. However, there are many obstacles to achieving this in practice, not least the lack of financial resources in many countries.

The Way Forward

Greenhouse gas emissions come from almost every human activity. Since deforestation contributes so significantly to anthropogenic global carbon emissions, the protection and conservation of forests is a highly effective form of mitigation. Protecting forests is key to maintaining the large stocks of carbon contained in them.

Actions to reduce the rate of deforestation can have an immediate impact on CO_2 emissions and are therefore likely to be a priority measure in the short to medium term. Actions to create new forests – either through afforestation or reforestation – provide complementary opportunities to mitigate emissions by carbon sequestration and are likely to become significant measures in the longer term. A number of mechanisms are already in place to assist delivery such as the Global Partnership on Forest Landscape Restoration which brings together governments, international organizations and practitioners to promote and share best practice in forest restoration programmes around the world.

Strategies for the forest sector to combat climate change should not only include actions to reduce emissions from deforestation, but also measures to support forest expansion and the sustainable management of existing forests, for example through the encouragement of sustainable forestry practices. They should, therefore, cover the following actions:

- Conservation of carbon stocks by **reducing deforestation.**
- Conservation of carbon stocks by the **sustainable management** of existing forests.
- Sequestration of carbon through the restoration of forests by **afforestation and reforestation.**
- Substitution of fossil fuel carbon emissions through an increased, sustainable **use of biomass for energy**.
- Substitution of carbon emissions associated with materials with higher embedded energy by a greater and sustainable **use of wood products.**

At the global level, there is also a need for the climate change negotiations and those taking place on forests, biodiversity, desertification and wetlands to work together to achieve maximum effect. At the national level, there will be real challenges in many countries to achieve the transition away from those activities which result in deforestation to measures which ensure that existing forests are conserved and managed sustainably and that the forest area is increased through afforestation and reforestation. For sustainable forest programmes to be successful, they will need to be part of wider, integrated land use and natural resource management programmes.

The United Nations Forum on Forests provides a focal point for addressing the issue of the sustainable management of forest resources. It has developed a series of practical proposals for action. Many countries have national forest programmes in place that take a broad cross-sectoral approach to the sustainable management of forest resources. The UNFF has led the way in developing systems for monitoring using criteria and indicators of sustainable forest management. These programmes will need to be configured to tackle the main drivers of deforestation and unsustainable land use. In many countries, however, the programmes either do not exist or have not been implemented.

Actions to protect, conserve and manage forests sustainably incur costs and require the commitment of resources. The pressure for deforestation is greatest in a small number of developing countries, but all countries gain from maintaining those forest resources that are providing global public goods. There is therefore a strong case for compensating countries for conserving all or part of their forest resources.

In addition to the crucial role that forests play – and could play – in climate change mitigation, they provide many other goods and services to society. These include timber and non-timber products, food and medicines, soil and water protection and conservation, biodiversity conservation and recreational resources. New forests can also contribute to adaptation, by alleviating flooding and erosion, protecting species and biodiversity, and contributing to socio-economic development. Forests around the world are increasingly being managed for multiple purposes to utilize these values. If managed sustainably, the world's forests can not only contribute significantly to climate change mitigation but also to national economies and the well-being of current and future generations.

It is increasingly recognized that taking action to protect forests is too important to wait until the next commitment period. New institutional, financial and market mechanisms are needed as part of a much broader range of actions to reduce deforestation and restore degraded forests, both as part of, but also outside, the framework of the Kyoto Protocol. Large-scale pilot projects to test these new measures are needed.

At this time, many countries lack the financial resources – and some the political will or necessary governance structures – to be able to deliver. If, as seems likely, current concerns about climate change mitigation continue to escalate on the international political agenda, it is possible, indeed probable, that significant new financial resources will be mobilized allowing the implementation of sustainable forest management programmes. These resources are likely to come from a range of sources, not only governmental but also from the private sector and civil society, and covering both market and non-market mechanisms.

There is reason to be optimistic. The forestry community has the knowledge and expertise to manage forest resources sustainably to deliver multiple goods and services to society. This knowledge should be used to influence the design of both sustainable forestry and climate change initiatives and to put them into practice. This expertise should be used in those international forums where decisions on forests and climate change are made. The international forums on forests, such as the UNFF, also need to create space in their agendas to influence policy on climate change.

We need to build on the new momentum. A clear strategic response from the forest sector is now needed because forestry will become a major instrument for political and economic actions to tackle climate change and to deal with its consequences. Taking action to mobilize resources and develop practical measures to reduce the rate of deforestation, to restore forests in areas where they have been lost or heavily degraded, and to manage the world's forests on a sustainable basis is both essential and urgent.

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