# Forests, Carbon and Climate Change

## - Local and International Perspectives -

Proceedings of the COFORD conference held at the
Glenview Hotel, Co Wicklow on 19 September 2007

Edited by Eugene Hendrick and Kevin G. Black

COFORD, National Council for Forest Research and Development
Arena House
Arena Road
Sandyford
Dublin 18
Ireland
Tel: + 353 1 2130725
Fax: + 353 1 2130611


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# Foreword

One of the most important scientific achievements of the past 150 years is the insight that has been gained into how the global climate works. As in all science there are still unanswered questions, but enough has become known for the Intergovernmental Panel on Climate Change (IPCC) to predict that the earth's surface temperature is likely to warm by between 1.1 and 6.4°C during this century. If left unchecked, global warming and the impact it will have on weather patterns, will, many scientists and economists believe, result in drastic consequences for human society. To paraphrase the UK Stern Report on climate change - failure to act will result in future costs many times what needs to be spent now.

Despite scientific and policy debate as to the causes and solutions for climate change there is no denying that levels of greenhouse gases, principally carbon dioxide, have increased since the industrial revolution and continue on a sharp upward trajectory. Before the early part of the last century most of the increase in emissions came from deforestation, and although fossil fuel combustion has since become the main culprit, deforestation still accounts for close to 20% of the annual greenhouse gas increase. While it is part of the problem, land use and forestry is also part of the solution to global warming: by conserving and wisely managing remaining untouched forests, by establishing new forests to remove carbon dioxide from the atmosphere, and by providing renewable wood energy and raw materials.

The potential contribution of forestry to removing carbon dioxide is estimated by the IPCC report as 1200 million tonnes of carbon dioxide per year – a significant level when one considers Ireland's annual emissions are currently 70 million tonnes. Over the longer term the potential is many times higher. Trees and plants have evolved to be highly efficient at removing carbon dioxide from the atmosphere – in fact the world's forests contain more carbon dioxide than is present in the entire atmosphere.

It comes as no surprise therefore that maintaining, managing and extending the global forest carbon store is one of the key policies of the UN Convention on Climate Change, agreed in 1994. Such activities are an essential part of the policy response to climate change. At the national level land use policy needs to reflect this reality and provide a sustained level of investment to leverage increased involvement by landowners and business in forest enterprise.

These conference proceedings address policy and scientific issues connecting forests and climate change. While the primary focus is on how forests and forestry practice can reduce levels of greenhouse gases in the atmosphere - and how this contribution can be scientifically assessed – the issue of how climate change is impacting on forests is also covered. The climate change policy response needs to deal with these two separate but closely related facets – how forests can mitigate climate change and how they can adapt to a changing climate.

Policy makers and practitioners should find much that is useful in these pages. The aim is to make the topic of forests and climate change more accessible, and provide a reference point for further consideration of an issue that is likely to stay high on the policy agenda over the coming years.

Dr Eugene Hendrick
Director

Michael Lynn
Chairman

# Réamhfhocal

Ceann de na héachtaí eolaíochta is tábhachtaí atá bainte amach le 150 bliain anuas ná an léargas a fuarthas faoi conas a oibríonn aeráid na cruinne. Ar an mbonn céanna le gach cineál eolaíochta tá ceisteanna gan freagra fós ann, ach tá go leor eolais faighte ag an bPainéal Idir-Rialtasach ar an Athrú Aeráide (IPCC) chun a thuar go bhfuil gach cosúlacht ann go dtéifidh teocht dhromchla na cruinne idir 1.1 agus 6.4°C le linn an chéid seo. Mura dtabharfar aghaidh air, creideann a lán eolaithe agus eacnamaithe go mbeidh droch-thorthaí ag téamh domhanda agus an tionchar a bheidh aige ar phatrúin aimsire don sochaí daonna. Chun athinsint a dhéanamh ar Thuarascáil Stern na Ríochta Aontaithe um athrú aeráide - cosnóidh an easpa gnímh i bhfad níos móamach anseo ná an méid atá riachtanach le caitheamh anois.

D’ainneoin dhíospóireacht eolaíochta agus beartais faoi na cúiseanna agus na réitigh ar athrú aeráide, ní féidir a shéanadh go bhfuil méadú tagtha ar leibhéil gháis cheaptha theasa, go háirithe dé-ocsáid charbóin ón réabhlóid thionsclaíoch agus leanann siad ar aghaidh ag méadú go géar. Roimh an chuid luath den chéad seo caite tháinig an chuid is mó d’astuithe ó dhíchoilltiú agus cé gurb é dó breosla iontaise an chúis is mó ó shin, tá díchoilltiú ciontach as beagnach 20% de mhéadú gháis cheaptha theasa in aghaidh na bliana. Cé gur chuid den fhadhb í, is cuid den réiteach ar théamh domhanda iad úsáid talún agus foraoiseachta chomh maith: trí na foraoisí atá fágtha nach bhfuil scriosta a chaomhnú agus a bhainistiú go ciallmhar, trí fhoraoisí nua a bhunú chun dé-ocsáid charbóin a bhaint den atmaisféar agus trí sholáthar fuinneamh adhmaid in-athnuaite agus amhábhair.

Meastar de réir tuarascáil IPCC gur rannchuid 1200 milliún tonna dé-ocsáid charbóin in aghaidh na bliana a d’fhéadfadh a bheith ag foraoiseacht i mbaint dé-ocsáid charbóin – leibhéal suntasach nuair a bhreathnaíonn tú ar astuithe na hÉireann in aghaidh na bliana faoi láthair – 70 milliún tonna. Tá an poitéinseal i bhfad níos mó thar tréimhse níos faide. Ní haon chúis iontais é seo mar tá éabhlóid tagtha ar chrainn agus ar phlandaí agus tá siad an-éifeachtúil i mbaint dé-ocsáid charbóin den atmasféar – tá níos mó dé-ocsáid charbóin i bhforaoisí na cruinne, creid nó ná creid, ná atá san atmaisféar uile.

Ní haon chúis iontais dá bhrí sin gurb é príomhbheartas Choinbhinsiún na NA faoi athrú aeráide ná cothabháil, bainistiú agus leathnú stór charbóin fhoraoise na cruinne, comhaontaithe i 1994. Tá gníomhaíochtaí dá leithéid mar chuid ríthábhachtach den bheartas freagrachta ar athrú aeráide. Ag an leibhéal náisiúnta, tá sé riachtanach go léiríonn beartas úsáid talún an réaltacht seo agus go soláthraítear leibhéal infheistíochta marthanach chun níos mó bainteacht i measc úinéirí talún agus lucht gnó a chothú i bhfiontraíocht fhoraoise.

Tugann na himeachtaí comhdhála seo aghaidh ar shaincheisteanna eolaíochta agus beartais a nascann foraoisí agus athrú aeráide le chéile. Cé gurb é an príomhfhócas ná an chaoi ar féidir le foraoisí agus foraoiseacht leibhéil gháis cheaptha theasa san atmaisféar a laghdú – agus conas is féidir an rannchuid seo a mheas ó thaobh na heolaíochta de - clúdaítear an saincheist faoi cén tionchar atá ag athrú aeráide ar fhoraoisí chomh maith. Tá sé riachtanach don bheartas freagrachta le haghaidh athrú aeráide déileáil leis na gnéithe ar leith seo ach a bhfuil baint acu lena chéile – conas is féidir le foraoisí athrú aeráide a mhaolú agus conas is féidir leo oiriúnú d’aeráid atá ag athrú.

Ba chóir do lucht déanta beartais agus cleachtóirí neart ábhar úsáideach a aimsiú sna leathanaigh seo. Is í an aidhm atá ann ná topaic na bhforaoisí agus athrú aeráide a shimpliú agus pointe tagartha a sholáthar chun an saincheist a mheas níos mó, saincheist a bheidh tús áite aige ar an gclár oibre beartais de réir cosúlachta sna blianta atá amach romhainn.

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| An Dr Eugene Hendrick<br>Stiúrthóir | Michael Lynn<br>Cathaoirleach |

# Forests and the UNFCCC process - an overview

Eugene Hendrick
COFORD

## Abstract

Forests are a key component of the global carbon cycle and have a role to play in mitigating climate change. Emission reductions are, however, the most effective way to tackle rising levels of greenhouse gases. The United Nations Framework Convention on Climate Change (UNFCCC) addresses these issues and provides the negotiation forum for the development of binding emission reduction targets, as set out in the Kyoto Protocol. Forestry is mainly addressed under Articles 3.3 (afforestation, reforestation and deforestation) and 3.4 (forest management) of the protocol, while the detailed rules to implement the articles are set out in the Marrakesh Accords and the common reporting formats of the UNFCCC. The protocol also provides for the establishment of afforestation and reforestation projects in developing countries under Article 12 - the Clean Development Mechanism. However, to date, just one project has been registered.

Over the past two years the forest process under the UNFCCC has begun to deal with reducing emissions from deforestation (RED) in developing countries, one of the largest global sources of greenhouse gas emissions. Recent analyses in the Stern Report and the Fourth Assessment Report of the Intergovernmental Panel on Climate Change show that measures to reduce deforestation would be highly effective, in terms of marginal abatement cost.

Harvested wood products and how they are treated in terms of emissions and changes in stocks is another important issue under consideration by the UNFCCC. Currently, the accounting assumption is that all carbon in harvested wood is immediately emitted as carbon dioxide to the atmosphere. While this is incorrect where there is a gradual increase in stocks of harvested wood products, accounting for wood products is complicated as to where and when emissions from harvested wood will be accounted for.

As well as their role in mitigating climate change, forests have a role in adaptation to global warming and its adverse effects. A special Adaptation Fund, under the Global Environment Facility GEF, is financed from a share of proceeds (2%) of certified emission reductions (CERs) issued from CDM projects. A number of forestry-related adaptation projects are being funded under this mechanism.

## Forests and the global climate system

Two facts stand out to illustrate the vital role that forests and vegetation play in the global carbon cycle: first, forest ecosystems contain more carbon in their trees and soils than is present in the whole of the earth's atmosphere (Prentice et al. 2001) and second, carbon dioxide fluxes into and out of forests are of a comparable magnitude to the overall global forest stock - up to one third of global atmospheric carbon dioxide is taken up by plants each year, a proportion of which is assimilated and becomes plant biomass (Ciais et al. 1997).

These insights point to the critical importance of conserving forest carbon stocks, and the potential role that forests have in sequestering carbon dioxide and in mitigating climate change.

## Forests and the mitigation of climate change

Globally, it is estimated that historic $CO_2$ losses from soils and vegetation have been about 625 Gt (billion tonnes) (Houghton 2003a, 2003b, 2005). Avoiding future carbon stock losses and replacing historic losses therefore have a significant potential to reduce atmospheric $CO_2$ levels. However, the scale of the mitigation effect that these measures offer will be constrained by economic, technical and social factors.

The Forestry Chapter of the Fourth Assessment Report of the IPCC (Nabuurs and Masera et al. 2007) deals with the scale issue and constraints, and estimates that by 2030 the economic potential of a combination of mitigation measures (afforestation, reduced deforestation, forest management, agroforestry, and bioenergy) could provide an additional sink of around 3150 Mt (million tonnes) $CO_2$/yr. In the short term, the potential is much smaller, about 1180 Mt $CO_2$/yr by 2010. The point is that measures such as avoiding future deforestation and replacing lost carbon stocks can, at a cost, contribute to mitigating emissions of greenhouse gases.

Comparing the reductions that forestry related mitigation measures can offer, 1-3 Gt $CO_2$/yr, with current annual emissions of carbon dioxide of 26 Gt $CO_2$/yr (IPCC 2007), shows, however, that the primary emphasis in tackling climate change must be on reducing emissions. Reducing levels of deforestation and increasing forest cover and other measures will make an impact, but essentially they only offer mitigation scope over a limited period of time, and have a subsidiary role compared with emission reductions (Smith 2003). Sinks are also at risk to reversal, through factors such as fire and land clearance, and indeed the impact of climate change itself.

Forestry-related mitigation measures should, furthermore, be complementary to overall forest policy goals. Expansion of forest cover, one of the core aims of Irish forest policy over the decades, was a policy mainly directed at building up a commercial forest estate, but now has an additional role in supporting the aims of the UNFCCC and the Kyoto Protocol. Central to both the expansion of the forest estate and efforts to mitigate climate change is the need to sustain existing forest cover and the practice of sustainable forest management (see discussion on Convention).

## Background to the Convention

The genesis of the United Nations Framework Convention on Climate Change – the UNFCCC - dates back almost three decades to the First World Climate Conference in 1979, which identified climate change as an urgent world problem and issued a declaration calling on world governments to anticipate and guard against potential climate hazards. Around the same time a World Climate Programme was established, steered by the World Meteorological Organisation (WMO) and other organisations.

Over a decade later, the Toronto Conference on the Changing Atmosphere recommended setting up a global framework convention to protect the atmosphere. That same year, 1988, saw the UN adopt Resolution 43/53, which determined that *…necessary and timely action should be taken to deal with climate change within a global framework…* Another key development in 1988 was the establishment of the Intergovernmental Panel on Climate Change (IPCC) by the WMO and the UN Environment Programme to assess the magnitude and timing of changes in climate, estimate their impacts and present response strategies.

From this point forward the pace of the international process began to quicken, particularly following the publication by the IPCC of its First Assessment Report on the state of the global climate in 1990 (IPCC 1991), which strengthened the scientific basis about the impact of the acceleration in greenhouse emission levels. In order to address the findings of the report at the policy level the UN established an Intergovernmental Negotiating Committee (INC) for a framework convention on climate change. Work progressed quickly, and by May 1992 the INC had finalised and agreed a convention text. It was launched at the Rio Earth Summit, where it was signed by 154 countries, including Ireland. The Convention entered into force in March 1994 and was ratified by Ireland the following month.

## The role of the UNFCCC

As set out in Article 2 the ultimate objective of the Convention is … *to achieve, in accordance with the relevant provisions of the Convention, stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.*

The ultimate decision making body of the UNFCCC is the Conference of the Parties – the COP – supported by the two permanent subsidiary bodies: the Subsidiary Body for Scientific and Technological Advice (SBSTA), and the Subsidiary Body for Implementation (SBI). SBSTA is advised by the Intergovernmental Panel on Climate Change on a range of scientific issues, mainly through the global climate change assessment reports, and through the development of guidelines for national greenhouse gas inventory reports, and associated good practice guidance.

## The forest process within the UNFCCC

Ultimately, the UNFCCC is a policy making body that is built on political engagement and agreement. Discussions on science-related and land-use climate change issues need to be seen in that context, playing an advisory role to the political process.

Most of the technical and policy related discussions in relation to forests take place under the auspices of the SBSTA, whose overall role is to provide the COP … *with timely advice on scientific and technological matters relating to the Convention.* One of its most important roles is to discuss and agree the climate assessment reports of the IPCC. It also organises work and detailed negotiations on mechanisms and other policy measures to tackle climate change. These endeavours are facilitated through formal and informal contact groups during the meetings of the UNFCCC and the SBSTA.

The SBSTA agenda has a number of longstanding items on forests and related issues, and it has recently been expanded by taking on the issue of reducing emissions from deforestation (RED) in developing countries (see *The big issue - deforestation*). Overall, the agenda provides the framework for negotiations on forestry issues, and COP decisions can only be taken in relation to an agreed agenda item - the climate change negotiation process works therefore in a structured way, and decisions are based on strong political input and direction.

EU input to the SBSTA process is co-ordinated through the Working Party on the International Environment (Climate Change). A number of expert groups report to the working party, including the Sink Experts Group, which deals mainly with forestry-related issues. Within the six-month rotating EU Presidency, member states take it in turn to lead on climate change issues in the UNFCCC process and related areas. Negotiations on individual issues mostly span more than the six-month period, and the topics discussed require in-depth knowledge of both technical and policy issues. For these reasons, a system of nominating and agreeing issue leaders and lead negotiators for individual topics was introduced during the Irish Presidency in 2004. It has proven to be highly effective. In the sinks area two-person negotiation teams cover the following topics:

1. reduced emissions from deforestation and land use, and change and forestry post-2012,
2. land use, and land-use change and forestry, and the clean development mechanism (CDM) under Article 12 of the Protocol,
3. reporting on land use, land-use change and forestry under the Convention and the Kyoto Protocol,
4. harvested wood products, and
5. co-operation with other Rio Conventions (such as the Convention on Biological Diversity).

## Forest sinks and reservoirs[1] and the Convention

While measures related to forest sinks come under the Kyoto Protocol, sinks and reservoirs are also dealt with in Article 4 (1) (a) of the Convention:

*Each of these Parties* [developed countries] *shall adopt national policies and take corresponding measures on … protecting and enhancing its greenhouse gas sinks and reservoirs*.

The extended Article 4 provides much of the basis for the Kyoto Protocol, including key elements such as the since-1990 emissions baseline, and the wording on sinks and reservoirs sets the tone for Articles 3.3 and 3.4 of the protocol, which deal with afforestation/reforestation and forest management, respectively.

Overall, sinks and reservoirs of terrestrial carbon have an important place in the Convention and are referred to 13 times, most explicitly in Article 4 (1) (d): *All … Parties shall … Promote sustainable management, and promote and co-operate in the conservation and enhancement, as appropriate, of sinks and reservoirs of all greenhouse gases not controlled by the Montreal Protocol, including biomass, forests…*

Translating these policies into national circumstances provides a further basis for the sustainable forest management (SFM) paradigm which is a central tenant of national forest policy (Forest Service 2000). In effect, the convention complements SFM policies and practice that protect existing forests. Conservation of forest cover and its expansion through afforestation have equal importance in the convention. This makes good sense in the light of the accounting rules under

[1] As defined in the Convention a "reservoir" means a component or components of the climate system where a greenhouse gas or a precursor of a greenhouse gas is stored, while a "sink" means any process, activity or mechanism which removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere.

Kyoto, particularly where deforestation is concerned, and which results in an immediate and accountable loss of carbon stocks.

## Kyoto and Marrakech - outlining the approaches and rules for the inclusion of sinks

While forests feature prominently in the convention, it is under the Kyoto Protocol that the legal basis for forests as a compliance tool for greenhouse gas emission targets is set out, particularly in Articles 3.3 and 3.4 which deal with afforestation/deforestation and forest management respectively. It is not the objective here to explain the details of how and why forests are treated under the Kyoto Protocol – only to point out that while the protocol was a triumph for negotiation and compromise it did inevitably leave a lot of issues unresolved; which later meetings of the UNFCCC had to resolve. In the understated words of the UNFCCC Handbook (UNFCCC 2006) … *Time constraints prevented COP 3 [Kyoto] from working out the details of how the Kyoto Protocol should operate in practice.*

After Kyoto the UNFCCC went about working out the details of how to operationalise reduction targets and inclusion of sinks. This work set the scene for COP 6 in 2000 in The Hague. During the lead-in to the meeting, the EU was concerned to limit the contribution of forest sinks to Kyoto compliance, keeping the focus on reduction of emissions of greenhouse gases. This was especially the case for forest management in Article 3.4, which because of the sheer scale of carbon sequestration in forests in developed countries, would have seriously undermined the need for emission reductions.

In the event, agreement was not reached at The Hague; sinks were the main reason, mainly because ways to include forest management (Article 3.4) proved too difficult to resolve in the timeframe of the meeting. The main concern was the scale of the offsets that could arise as a result of forest management. Forest sinks in the Clean Development Mechanism - Article 12 - was another issue of contention.[2]

Understandably, there was a strong determination that the sink issue would be sorted out when the parties reconvened at COP 6 *bis* in Bonn the following May. After protracted and difficult negotiations the issue was resolved – by placing caps on forest management. Levels were arrived at by using an 85% discount[3] on net forest growth and a 3% of base year emissions cap for some Parties (including the EU Member States); for others national circumstances were taken into account. While the amounts for some Parties, such as the Russian Federation for example, may seem very generous (close on 65 million tonnes of $CO_2$/yr), Russia was vital to having the protocol ratified and entering into force.

Election of forest management is voluntary, but once a Party elects it, the areas included (pre-1990, managed forests) enter the accounting framework and are there for the foreseeable future: once in, always in. Furthermore, stock changes on these lands must be reported in a transparent manner, and if and when losses exceed the cap they must be added to annual emissions. Such concerns, related to the impact of forest fire and insect infestation on carbon stocks, must have been foremost in the decision by the Canadian Government in 2007 not to elect forest management, despite the potential to use up to 14 million tonnes of $CO_2$ per annum from its managed forest to contribute to national greenhouse emissions compliance for the first commitment period 2008-2012. Depending on the outcome of the post-2012 negotiations, parties who have not elected forest management may be able to do so, though the modalities and accounting framework have yet to be agreed.

As well as arriving at an agreement on the caps for forest management under the Protocol, the COP 6 *bis* process developed the basic framework for forest sinks, and fleshed out key parts of the detail required to operationalise Articles 3.3 and 3.4 in terms of definitions, determination of forest areas and forest carbon pools. These and other issues are covered in FCCC/KP/CMP/2005/8/Add.3, first issued as part of the Marrakesh Accords package at COP 7 in 2001, and in many ways is the key document on forests in the UNFCCC process.

[2] The Clean Development Mechanism is set out in Article 12 of the Kyoto Protocol … The purpose of the clean development mechanism shall be to assist Parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the Convention, and to assist Parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments under Article 3.

[3] The 85% discount was applied to remove anthropogenic influences on forest growth.

*Common reporting formats and IPCC Good Practice Guidance for LULUCF – fleshing out the details for the treatment of forest sinks*

Treatment of sinks in the UNFCCC process can be seen as a pathway leading from the Convention, to the Protocol, to the Marrakesh Accords and finally to the Common Reporting Formats[4] (CRF), which are outlined in FCCC/CP/2004/10/Add.2.

All of the steps along the path were subject to intense negotiation, which became increasingly painstaking as the level of detail increased. Even a casual examination of the CRF for the forestry sector indicates the level of detail that is contained in the reporting tables, which must be completed by all Parties to the Convention. Each and every item in the tables was discussed and agreed as part of the process. This illustrates the benefit of having specific lead negotiators to deal with these issues, discussion of which can extend to several years.

One of the vital inputs to the detailed negotiation process on the CRF forest sink tables was the Good Practice Guidance for Land Use, Land-Use Change and Forestry (LULUCF) (IPCC 2003). Indeed, the Good Practice Guidance (GPG) is in itself one of the main tools that is used to support reporting on forest sinks; and again the decision to use the GPG was the subject of prolonged and protracted negotiation.

*Sinks in the Clean Development Mechanism*

As well as Articles 3.3 and 3.4, the Marrakesh Accords deals with sinks in the Clean Development Mechanism (CDM). Under the CDM, developed countries can invest in forestry and other projects in developing countries and offset part of their domestic emissions against verified and registered emission reduction units arising from the project.

During the negotiations leading up to the agreement of the sinks CDM package, there was considerable debate on whether emission reductions from projects aimed at conserving carbon stocks in existing forests in developing countries, mainly through avoided deforestation, should be included in the accounting framework. The EU and other Parties opposed such inclusion on the basis of potential scale, and concerns about leakage, whereby reductions in deforestation in one region of a country may lead to increases elsewhere in the same, or an adjacent, country. In the event CDM forestry activities were confined to afforestation and reforestation, and their contribution to compliance was limited to one percent of base year emissions for all Parties (see FCCC/KP/CMP/2005/8/Add.1and Add.3).

Detailed negotiations on the CDM modalities were concluded at COP 10 in Buenos Aires, after considerable progress had been made at the previous SBSTA in Bonn, under the Irish EU Presidency. Included in the CDM package are modalities for small-scale projects (limited to 8 kilotonnes of $CO_2$/yr), which are less onerous than larger projects and are targeted at low-income communities. Some African countries and other Parties wish to raise the annual limit for small-scale projects, to make them more economically feasible. Based on an indicative price of €5/tonne $CO_2$ for temporary CERs from small-scale projects, the annual income from a small-scale project would be about €40,000. Despite the fact that small-scale afforestation/reforestation projects pay reduced fees, and have simplified modalities, the net income to communities and project developers may not be sufficient to result in a significant number of projects coming on stream - time will tell.

Another barrier to investment in CDM forestry projects is that the offsets are specifically excluded from the EU Emissions Trading Linking Directive. A number of EU Member States have argued that the directive should be amended to include CDM forestry projects, given their developmental potential.

To date, just one (large-scale) CDM forestry project has been formally approved, comprising 4,000 ha of reforestation in the Pearl River Basin, in Guangxi province in China. Eight methodologies have been approved and seven projects are under validation. In addition, four small-scale project methodologies under currently being validated (Sanz, per comm. 2007).

*The big issue – deforestation*

Over the last 8-10 millennia about half the world's forests have disappeared, mainly as a result of land conversion to agriculture. Meanwhile, deforestation losses continue at a rate of 13 million ha/yr, while the net loss (after taking afforestation, landscape restoration and natural expansion of forests into

4 The common reporting format is a standardised format to be used by Parties for electronic reporting of estimates of greenhouse gas emissions and removals and any other relevant information (FCCC/KP/CMP/2005/8/Add.3).

account) was running at 7.3 million ha/yr over the period 2000-2005 (Nabuurs and Masera et al. 2007). Losses are concentrated in tropical forests in developing countries.

To put deforestation patterns in a global and historic context it is well worth remembering that Ireland, and indeed other developed countries, were no strangers to deforestation in the past. Following many centuries of forest loss, forest cover in Ireland had fallen to just 1% of the land area at the beginning of the 20th century. Recovery only began in earnest from the 1920s, and after successive decades of state, and more recently private, afforestation it has now reached the current level of 10%. Similar patterns of forest loss/deforestation and recovery have occurred throughout Europe and in other developed countries; even Finland and Sweden, which today have well over two thirds of the land area under forest, suffered from extensive forest clearance in the past and gradually restored forest cover over many decades.

While estimates of the precise scale of forest removal in Ireland is a topic of scholarly debate, a reasonable estimate is that about 60% of the land surface of the island, or about 5.1 million ha, has been denuded of tree cover by man (excluding the current area of forest). Assuming a standing carbon stock of 500 t $CO_2$/ha (within the range set out in Table 3A.1.2 of IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003)) removal on such a scale would have resulted in emissions of about 2.5 Gt (billion) tonnes of $CO_2$. To put this into perspective, Ireland's annual emission of greenhouse gases is in the region of 70 Mt (million) tonnes of carbon dioxide – so the historic loss of forest cover in Ireland is equivalent to 35 years of current annual emissions of greenhouse gases.

Returning to the global issue, current estimates indicate that deforestation in developing countries contributes about 20% to annual emissions of greenhouse gases (Baumert et al. 2005). Foremost, therefore, in effecting the climate change mitigation role of forests is to constrain global deforestation trends. The UK's Stern report (Stern 2006) on the economics of climate change makes this point:

*Curbing deforestation is a highly cost-effective way of reducing greenhouse gas emissions and has the potential to offer significant reductions fairly quickly. It also helps preserve biodiversity and protect soil and water quality. Encouraging new forests, and enhancing the potential of soils to store carbon, offer further opportunities to reverse emissions from land-use change…Compensation from the international community should be provided and take account of the opportunity costs of alternative uses of the land, the costs of administering and enforcing protection, and managing the transition.*

This conclusion is echoed in Forestry Chapter of the Fourth Assessment Report of the IPCC (Nabuurs and Masera et al. 2007):

*In the short term, this emission avoidance* [avoided deforestation] *offers the main mitigation option in the forestry sector, combining positive ancillary benefits in terms of biodiversity conservation, sustainable rural development, other environmental services, and probably adaptation to climate change as well.*

More recently, estimates by Gullison et al. (2007) indicate that reduced emissions from deforestation rates could contribute up to 10% towards a global stabilisation target of 450 ppm carbon dioxide. Such a concentration should constrain the rise in global temperatures to 2°C or below (Bernstein et al. 2007), the oft-quoted EU target.

In terms of the UNFCCC process the deforestation issue was, as outlined, part of the considerations when the CDM forestry package was being negotiated, but it was excluded, as pointed out, because of the leakage issue. So, when the CDM forestry package was finalised in 2004, it excluded measures to reduce deforestation, and was confined to afforestation and deforestation.

Given that deforestation is such a high profile issue, it was no surprise that Papua New Guinea and Costa Rica made a submission on the issue (FCCC/CP/2005/MISC.1) in 2005, which put it on the agenda of the COP 11 in Montreal. Key to the new proposal is that it proposes national baselines, which together with wide participation by developing country Parties, should address the leakage issue.

Since Montreal, deforestation has been under intense negotiation, and will feature prominently at COP 13 in Bali in November 2007. A number of Parties are pushing strongly for a substantive outcome at COP 13, that would provide agreement on principles for inclusion of a mechanism to address deforestation, a way to link early action (pre-2012 pilot projects) to a post-2012 incentive framework, as well as deciding what methodological issues need to be addressed in the period leading up to 2012. Other Parties are seeking to widen the coverage of forestry activities in developing countries that would come under the

UNFCCC process, particularly those whose natural forest resource has remained largely unexploited, and therefore have little or no opportunity to reduce their deforestation levels. Other developing country Parties which now report net gains in forest cover, on foot of large-scale reforestation programmes, are also seeking ways to broaden the mechanism beyond avoided deforestation per se. All of these issues are part of the larger debate on the post-2012 framework, and will no doubt be addressed in that context.

The EU has stated its support for addressing the deforestation issue in the context of climate change in the conclusions of the February Environment Council: '*… emissions from deforestation in developing countries amount to about 20% of global* $CO_2$ *emissions and that concrete policies and actions as part of a global and comprehensive post-2012 agreement are needed to halt these emissions and reverse them within the next two to three decades, while ensuring the integrity of the climate regime and maximising co-benefits, in particular with regard to biodiversity protection and sustainable development, using synergies between the UNFCCC, CBD and CCD.* '

*Harvested wood products*

Currently, the Kyoto accounting framework uses the assumption that all harvested wood that leaves the forest is immediately lost back to the atmosphere as $CO_2$– the so-called default approach (IPCC 1996). Changes in carbon stocks in Kyoto forests are therefore reported net of harvest, apart from an exception to the rule for fast growing forests which will be harvested during the period 2008-2012, which says that such forest areas cannot be a source. Underlying the default assumption is that there is no increase or decrease in the harvested wood carbon pool for a particular Party. Clearly this is not the case for a number of countries, including Ireland, where stocks of harvested wood have been increasing (see FCCC/SBSTA/2005/MISC.9).

As well as the default approach there are a number of other approaches to reporting/accounting for greenhouse gas emissions from harvested wood products (HWP). They differ mainly with regard to where and when changes in carbon stocks or emissions are assumed to occur (UNFCCC 2003). Allocation of emissions from harvested wood products and changes in carbon stocks are issues that will need to be resolved if the default approach is to replaced in the future.

The IPCC has recently published new guidelines for national greenhouse gas inventories which includes a chapter on harvested wood products (Pingoud et al. 2006). The guidelines do not imply a preference for a particular approach and are intended for use in voluntary reporting under the Convention. One of their attractions is that they provide a methodology to derive five key variables which can be used for any of the approaches.

Given the interest of a number of Parties in the possible inclusion of harvested wood products post-2012, dialogue on the HWP issue will continue at future COPs. The issue is inextricably linked to the broader land use question and its inclusion post-2012. How emissions from HWP are allocated is clearly an important issue, as is how the different approaches treat emissions from the use of wood for energy.

## Adaptation, forests and the UNFCCC

This paper has focussed on mitigation aspects of forests as this has been the main preoccupation of the UNFFCC forestry process to date. Undoubtedly there are adaptation aspects to many forestry mitigation measures, and this is acknowledged in the Fourth Assessment Report, which says in Chapter 9 of the Working Group III report: '*Forest-related mitigation options can be designed and implemented to be compatible with adaptation, and can have substantial co-benefits in terms of employment, income generation, biodiversity and watershed conservation, renewable energy supply and poverty alleviation*' (Nabuurs and Masera et al. 2007).

The UNFCCC also contributes funding through its financial mechanism to the Global Environment Facility (GEF). A special Adaptation Fund, under the GEF, is financed from a share of proceeds (2%) of certified emission reductions (CERs) issued from CDM projects. A number of forestry-related adaptation projects are being funded under this mechanism.

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# New Zealand: Forest carbon reporting and the role of forests in climate change policy

Peter Stephens[1], Bryan Smith[2] and Roger Lincoln[1]

[1] Ministry for the Environment, New Zealand

[2] Ministry of Agriculture and Forestry, New Zealand

## Abstract

To meet land use, land-use change and forestry (LULUCF) reporting requirements under Article 3.3 of the Kyoto Protocol, New Zealand is developing a carbon reporting and accounting system. This system is called LUCAS (Land Use and Carbon Analysis System). New Zealand is using a plot-based system to inventory all forests, and a modelling approach to determine the amount of carbon in the forests. Where plots can not be accessed by field teams, scanning airborne LiDAR is being used. Maps of changes in land use since 1990 are being created by the use of satellite imagery and aerial photography.

Forestry is part of specific LULUCF activities under the Kyoto Protocol. The Protocol requires developed countries to collectively reduce their greenhouse gas emissions to a prescribed level or to take responsibility for excess emissions. Net removals from the LULUCF sector can also be used to meet emission obligations.

New Zealand's target is to reduce greenhouse emissions to 1990 levels on average between 2008-2012. New Zealand has a high proportion (about 25%) of removals from forest sinks compared to total 1990 emissions. This, combined with nearly 50% of emissions coming from agriculture, makes New Zealand's greenhouse gas profile unique amongst developed counties.

Forestry provides many positive environmental outcomes that can help New Zealand mitigate the impact of climate change. A suite of forestry policies are being developed in New Zealand to address current, and post-2012, climate change and environmental issues.

## Introduction

New Zealand is a signatory to the Kyoto Protocol and the United Nations Framework Convention on Climate Change. Under the Kyoto Protocol, Article 3.3 is mandatory. New Zealand did not elect any Article 3.4 management activities. A requirement under Article 3.3 of the Protocol is annual reporting of carbon stock changes arising from land use, land-use change and forestry (LULUCF) activities. Reporting is required for the Protocol's first commitment period, from 2008 to 2012. Good Practice Guidance for LULUCF activities requires carbon stock changes to be estimated in an unbiased, transparent, and consistent manner. Further, uncertainties must be determined and these are required to be reduced over time.

The forestry sector makes a major contribution to New Zealand's economy and environment. Newly planted production forests are referred to as 'forest sinks' because they remove carbon dioxide ($CO_2$) from the atmosphere. On the other hand, harvest and deforestation (conversion of forest land to another land use) releases $CO_2$.

The business of forestry must compete in an international market place. New Zealand exports wood products to over 30 countries, with total export earnings for the year to March 2006 of $3.2 billion or 11% of New Zealand's merchandise exports. The forest industry contributes about 3.3% of New Zealand's GDP and directly employs around 23,400 people. It also has substantial potential for export growth, with up to a third more wood available for sustainable harvest over the next few years.

Forestry delivers many positive environmental outcomes which can help us adapt to impacts of climate change. Forests can reduce flood peaks during major storms and rates of erosion by up to 90% compared to hill country land under pasture (Marden 2004). In terms of water quality, forests can reduce micro-organisms, sediment loads, nutrient runoff and moderate stream temperatures. These benefits of forests can be used to help land managers adapt to the climate change.

Forests and forestry also have a major role to play in mitigating climate change. As trees grow they absorb $CO_2$ from the atmosphere and store it in wood and other biomass components (and in soil). This process is recognised under the Kyoto Protocol by allowing new forests to generate forest sink credits. Over the first commitment period, New Zealand will generate about 78 million tonnes (net of harvest) of sink credits, which can be used to offset growth from other New Zealand greenhouse gas emissions. The forestry sector also produces renewable 'climate change friendly' products that can displace more energy intensive alternatives like concrete, steel and aluminium. On the downside, when forests are harvested and not replanted (deforestation) the carbon they once stored is released back into the atmosphere. In New Zealand, deforestation of plantation forests has increased rapidly in recent years, a trend that is expected to continue as land managers seek higher returns from their land use investment. There is virtually no deforestation of natural forest in New Zealand.

This paper firstly describes the forest carbon reporting and accounting system being developed to meet the requirements of the Kyoto Protocol. This system is called LUCAS (Land Use and Carbon Analysis System). New Zealand is using a plot based system to inventory all forests, and a modelling approach to determine the amount of carbon in the forests. Secondly, the paper outlines a balanced package of policy options the Government wants to put in place to simultaneously help reduce emissions from deforestation and to increase carbon sequestration through forest sinks.

## Forest carbon reporting

*Planted forest inventory*

To meet LULUCF reporting requirements, New Zealand is classifying forests into three categories: natural forest; forests planted prior to 1990; and forests planted after 31 December 1989 in to non-forest land. The latter category is referred to as 'Kyoto forests'. New Zealand forests to be measured under the Protocol have the following selected parameters: minimum area of 1 ha; at least 30% canopy cover; potential to reach 5 m in height; and a width of 30 m. New Zealand planted forests are comprised predominantly (89%) of radiata pine (*Pinus radiata*), with the remainder made up of other species, mostly (6%) Douglas fir (*Pseudotsuga menziesii*) (MAF 2006).

A plot-based forest inventory system has been developed for Kyoto forests. Circular plots, 0.06 ha in area, will be located within these forests on a systematic 4 km grid across New Zealand. Field access to the mostly privately-owned Kyoto forests is not guaranteed. Accordingly, airborne scanning LiDAR (Light Detection and Ranging) will be used to inventory those plots without field access. The relationship between plot based modelled carbon and LiDAR plot based metrics is shown in Figure 1. The relationship between the two is reasonable, with an $R^2$=0.80; RMSE error = 23 t (carbon) per ha (19%)) (Stephens et al. 2007).

*Forest carbon modelling*

Plot measurements are used as inputs to a New Zealand specific radiata pine growth model, the 300 Index (Kimberley et al. 2005) and a carbon allocation model, called C_Change (Beets et al. 1999). The key inputs to this growth model include: mean top height; basal area; tree age; and silvicultural regime (stocking (trees per ha), pruning, and thinning). Mean top height is the mean height of the 100 largest diameter stems per ha, and its method of calculation is described by Dunlop (1995). Mean top height is derived from plot tree total heights and stem

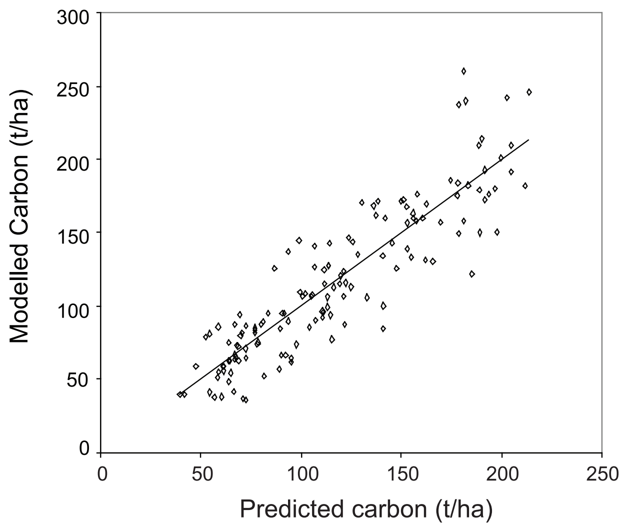


Figure 1. Predicted carbon using LiDAR-derived inputs versus modelled carbon using the 300 Index growth model and the C_Change carbon allocation model (n=140).

diameters measured in the field. LiDAR metrics used in predicting total carbon per plot are tree stocking, height and percent vegetation cover.

These two models can be linked, with the growth model used to parameterise the carbon allocation model. Under the Kyoto Protocol the four biomass carbon pools that must be reported are above-ground biomass, below-ground biomass, dead wood, and litter. The amount of carbon in each of the four biomass carbon pools, at any stage of tree growth and stand development, is determined by running these two linked models.

Once the carbon per carbon pool has been determined on a plot basis, a national average carbon density per ha for each of the carbon pools is then determined. These national average carbon densities are then used with the areal extent of land use, and over time and land-use change, to determine national carbon stock changes for the LULUCF sector.

Changes in soil carbon, related to changes in land use, are determined using a model developed for national-scale reporting under the Kyoto Protocol (Tate et al. 2005).

*Mapping land use and land-use change*

Medium spatial resolution (10-30 m) satellite imagery and aerial photography are the main sources of information being used to map land use, at the 1 ha scale, at 1990, and land-use changes between 1990, 2001, 2008 and 2012. Landsat TM (Thematic Mapper) is being used for the 1990 mapping, Landsat ETM (Enhanced Thematic Mapper) for the 2001 mapping, and SPOT 5 multispectral data for the 2008 and 2012 mapping. Existing land resource inventory and land cover maps are being used as ancillary datasets to assist in decision-making.

The intention is to also use satellite imagery to map forest harvesting and any land-use changes following harvesting (which can lead to deforestation). Currently daily coarse resolution (250 m) MODIS satellite data are being evaluated as a possible means of mapping forest harvesting on an annual basis. Satellite radar is another approach that may be evaluated.

## Forests in climate change policy

Forest sector activities can lead to both the absorption and emission of $CO_2$ and other greenhouse gases. The sector provides a major sink for greenhouse gases when new forests are planted. But the sector is also a major source of greenhouse gas emissions, mostly through carbon being released into the atmosphere as a result of deforestation.

The New Zealand Government intends to put a balanced package of policies in place that simultaneously helps to reduce emissions from deforestation and to increase $CO_2$ absorption through forest sinks. Government intends at least one afforestation policy and one deforestation policy.

*Encouraging afforestation*

Over a typical 27 year rotation, a hectare of mature radiata pine forest is estimated to absorb and store about 800 tonnes of $CO_2$. Under the Kyoto Protocol, New Zealand generates sink 'credits' from increases in carbon stocks over the first commitment period (2008-2012) in forests planted after 1990 in to non-forest land.

The Permanent Forest Sink Initiative (PFSI) has been announced by government. The PFSI provides an opportunity for landowners to establish permanent forest sinks and obtain tradable Kyoto Protocol compliant emission units in proportion to the carbon sequestered in their forests. Key features of the PFSI include:

- to be eligible for this initiative the land must not have been forested as at 31 December 1989,
- the forest must be "direct human induced .... through planting, seeding and/or the human-induced promotion of natural seed sources",
- limited harvesting of the forests established under this initiative is allowed on a continuous canopy cover basis,
- landowners will be expected to meet all the costs and risks associated with the PFSI, and
- agreements between landowners and the Government will be registered against land titles.

The Government has identified two further policy optigns to encourage greater levels of afforestation. These - along with a number of other climate change policy options covering the agriculture and forestry sectors - were released in a public discussion document in December 2006. Either of these afforestation options could work alongside the PFSI.

The first option is an Afforestation Grants Scheme. The second option would provide growers of new Kyoto Forests with a choice between an

Afforestation Grants Scheme or the devolution of Forest Sink Credits and their Associated Liabilities. Following an extensive consultation round with forest industry and other stakeholders, there was a preference for providing growers with a choice between an Afforestation Grant Scheme and devolved credits and liabilities.

The key features of the Afforestation Grants Scheme option include:

- the Government would retain all sink credits and associated liabilities (harvesting and deforestation liabilities) from a grant forest,
- grants would generally be allocated based on the highest expected amount of carbon sequestration for the lowest tender grant rate,
- sites with more co-benefits would be given higher priority in the allocation of grants, where co-benefits that would be considered for targeting include flood protection, erosion control, water quality improvement and biodiversity, and
- the payment of the grant would be covered by a contract between the Government and the applicant. If the grant forest was deforested within a set period of time from planting, the grantee would have to repay the grant.

A devolved credits and liabilities regime would operate along similar lines to the PFSI described earlier, though without the same level of restrictions on harvesting activities.

*Managing deforestation*

Under the Kyoto Protocol, New Zealand will incur costs when carbon stocks fall over the first commitment period for land deforested. After 2008, deforestation of a hectare of mature radiata pine forest is expected to be recorded as an emission of about 800 tonnes of $CO_2$ per ha in the national carbon account. That is equivalent to an emissions cost of about NZ$13,000 for each hectare of land deforested (assuming NZ$15.90 per tonne of $CO_2$). In recent decades the rate of deforestation of exotic forests is estimated to be not more than 2 - 4 percent of the area harvested each year.

In October 2002, following extensive consultation, the Government announced the following policy in relation to deforestation:

- the Government retain deforestation liabilities, provided these remain within a cap equal to 21 million tonnes $CO_2$ equivalent, being the carbon that would be released by the deforestation of approximately 10 percent of the area of forest reaching maturity during the first commitment period,
- in the unlikely event that significant deforestation may occur at levels above expectations, the Government will consider its policy options to manage emissions within the cap, including addressing issues such as,
  - how deforestation rights within the cap will be allocated,
  - how to monitor and enforce the deforestation cap, and
  - what actions the Government will take in the event the cap is exceeded.

Latest information suggests that there is a significant risk that the cap on deforestation liabilities will be breached without further policy intervention.

In the December 2006 discussion document described above, the Government identified four options to better manage deforestation. Two options involved a mix of incentives and penalties (a flat charge option and a tradable permit option) and the other two involved mainly regulation (using New Zealand’s resource management legislation, or new legislation to centrally determine deforestation levels).

Work has also commenced on a possible economy-wide emissions trading scheme. Over the coming months the issues of a possible afforestation grants scheme, devolving forest sink credits (and their associated liabilities) and managing deforestation are being considered in light of the work on emissions trading.

The Government is also studying feedback from the consultation process that has been conducted throughout the first half of 2007.

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# Ireland's forest carbon reporting system

Kevin Black

FERS Ltd.

## Abstract

National reporting requirements to the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto protocol relating to carbon (C) sequestration by Irish forests includes the estimation of changes in biomass, litter, dead wood and soil C stocks, over time. The national forest C inventory reporting procedure (CARBWARE) has, in the past, relied heavily on generalised stand-level yield models to simulate biomass C stock changes for different age classes and forest types. These initial estimates were subject to a high degree of uncertainty due to incomplete inventory statistics on major forest C pools. The newly established National Forest Inventory (NFI), GIS resources and research information from the COFORD-funded CLI-MIT programme now provide the opportunity to develop a state-of-the-art national reporting system that is transparent, verifiable and compliant with international reporting guidelines.

This paper describes the ongoing development of CARBWARE and provides some preliminary estimates of the forest sink capacity with specific reference to reporting requirements under the Kyoto Protocol.

## Introduction

Under the agreed terms of the Kyoto protocol, Ireland is committed to reduce greenhouse gas (GHG) emissions by 13% above the 1990-base year level over the period 2008-2012. Current estimates (1990-2004), however, suggest that emission levels are 23% above the 1990 level (McGettigan et al. 2006).

Article 3.3 of the protocol requires the reporting and accounting of carbon stock changes associated with land-use, land-use change and forestry (LULUCF). Newly planted forests (post-1990), in particular, offer the potential to offset $CO_2$ emissions in other sectors by taking up and storing carbon in forest biomass and soils. The sequestration potential of these forest sinks has been substantially enhanced by the establishment of more than 250,000 ha since 1990, following the introduction of afforestation grant schemes (Figure 1). Assuming a business as usual scenario, it is estimated that the contribution of national forests, under Article 3.3, may offset ca. 16% of the required GHG emissions for the first commitment period (2008-2012, Black and Farrell 2006). However, estimation of the extent to which forests sequester carbon in the mid to long-term is hindered by uncertainty due to spatial heterogeneity and temporal variability.

The Irish carbon reporting system (CARBWARE), initially described by Gallagher et al. (2004), was implemented to meet reporting requirements to the United Nations Framework Convention on Climate Change (UNFCCC) on all national forest sources and sinks. Whilst this model indicated the likely contribution of forests to national C storage (sink) potential, the system relied on the use of generalised stand growth models to describe changes in forest carbon stocks because of a lack of national forest inventory data. Subsequently, the availability of detailed NFI data and new research information now provide the opportunity to redevelop and improve estimates of national forest carbon stock changes.

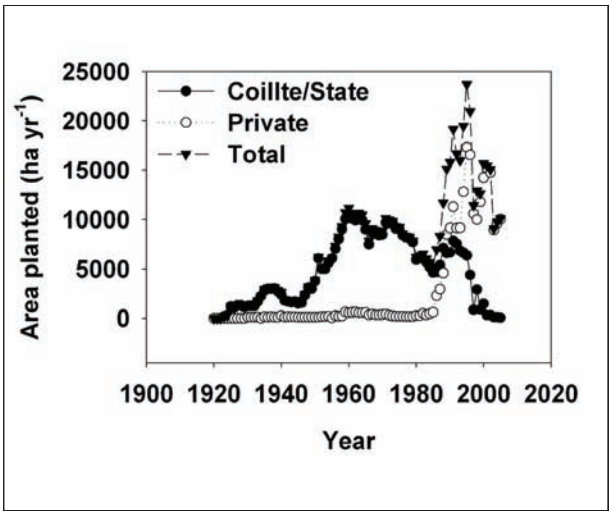


Figure 1: Trend in state and private afforestation since 1920 (Source: Forest Service).

## The CARBWARE system

Ideally, the most reliable method to estimate forest GHG gains and emissions is the use of inventory data, which are captured at regular and sufficiently frequent time intervals. However, CARBWARE currently adopts a combined modelling and forest inventory data use approach due to the poor temporal resolution of NFI data (i.e. only one inventory to date).

The CARBWARE model simulates the flow of carbon between forests, forest products and the atmosphere (Figure 2). The removal of $CO_2$ from the atmosphere as a function of forest growth is simulated using models parameterised for different species cohorts which exhibit similar growth characteristics. It will also include emission factors (decomposition) not normally captured by conventional inventory procedures, such as those associated with thinning and cultivation. Although the current national GHG inventory assumes that all wood products are immediately emitted to the atmosphere at harvest, the potential C storage in harvested wood products has been included in the model.

To scale up from stand estimates to national level the CARBWARE model uses multiple datasets, including the Forest Service forest inventory planning system FIPS, NFI, felling licence data, a GIS soil-landscape maps, ecological site classification productivity maps (CLIMADAPT, see Ray 2007, this publication). Other Forest Service databases will provide information on deforestation, wild fire, nitrogen fertilisation and harvest from thinning. The afforestation grant scheme database (iFORIS) provides digital maps with species attributes for all areas afforested since 1990.

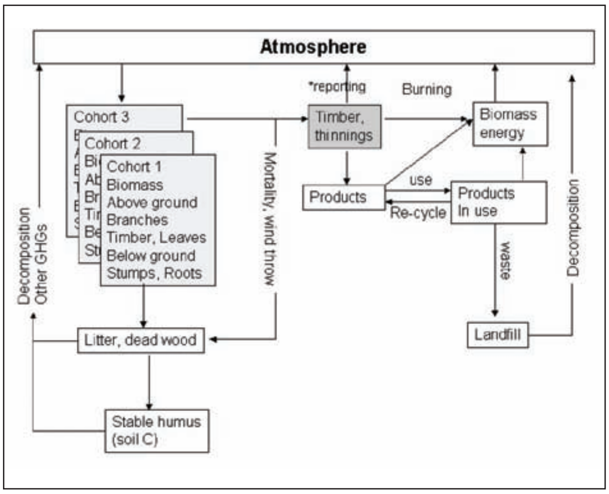


Figure 2. Flow diagram of proposed CARBWARE model including all components (for UNFCCC and Kyoto reporting, wood products are assumed to be a source at harvest).

Future repeat inventories, over a 5-year cycle, on permanent plots will provide the opportunity to directly estimate C stock changes over time for both Kyoto and UNFCCC reporting. CARBWARE models will then be used to interpolate stock change estimates between inventory years.

### *Forest growth models*

The current CARBWARE estimates of changes in biomass over time are based on modified Forestry Commission stand-level models (Edwards and Christy 1981) and research information from the previous COFORD-funded project (CARBiFOR I, see Black and Farrell 2006). The biomass model also simulates the changes in other C pools, such as litter, harvested wood and dead wood for different species and management scenarios (Figure 3), based on research information (Black et al. 2004, 2007; Tobin et al. 2006, 2007; Saiz et al. 2007).

### *Soils*

An analysis based on NFI data, CARBWARE estimates and a national soil database (Tomlinson et al., 2004) suggest that soils represent the largest store of carbon in Irish forests (90% of all forest C stocks).

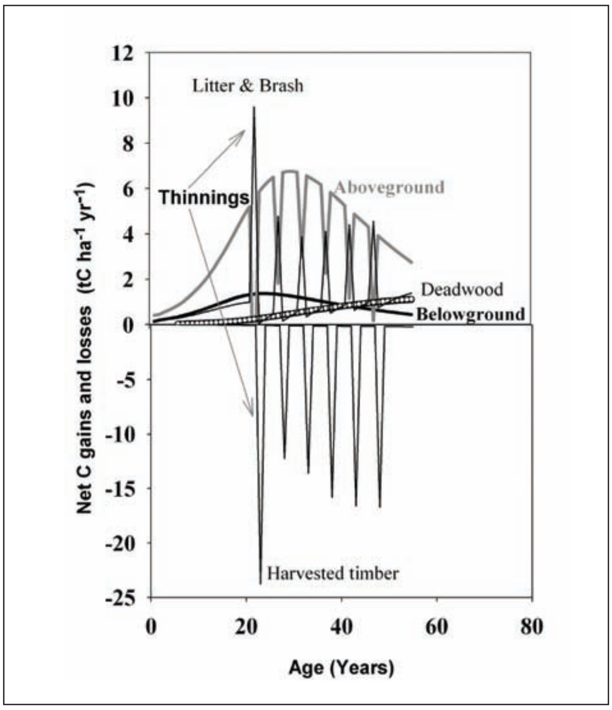


Figure 3. An example of a cohort output from the current CARBWARE growth model showing net gains (positive) and losses (negative) of major C pools during a first forest rotation (yield class 22 Sitka spruce at 2.5 m spacing, subjected to intermediate thinning at marginal thinning intensity).

The average carbon storage in soils (450 t C ha$^{-1}$) is considerably higher, when compared to that of most other EU countries, due to the large proportion of forests on peat soils (48%).

Small changes in C stocks in peat soils over the short to long term (5 to 50 years) are extremely difficult to measure because of the inherent soil C stock. The current CARBWARE system assumes soil C stock is expected to decrease (i.e. represent a C source) in peat soils following drainage and afforestation. This is due to the oxidation of organic matter following the creation of aerobic conditions. Alternatively, other studies suggest that most wet mineral soils represent a C sink (take up C) because of the accumulation of organic matter in these soils (Black et al. 2007; Black and Farrell 2006).

The soil sub-model component of CARBWARE is based on the assumption that soil C reaches a steady state after 20 years following land-use transition in to or out of forest. Soil C reference values (Tomlinson 2004) are currently derived from GIS soil type and land-use transition data bases (Figure 4). The soil C stock change factors following land-use transitions will be obtained from research information derived from the CLIMIT programme (see Byrne 2008, this publication) and/or default IPCC values.

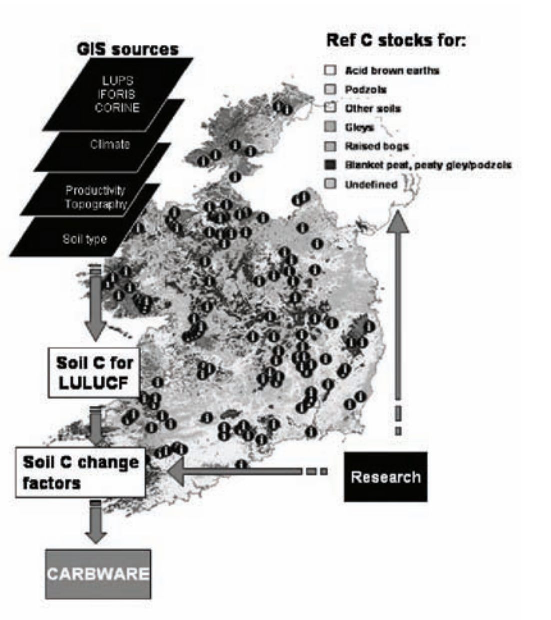


Figure 4: The soil carbon stock change reporting system. Black symbols indicate the position of paired sample plots which will be used to estimate changes in soil C stocks (see Byrne 2008, this publication).

*CARBWARE deliverables*

- An IPCC Good Practice Guidance for LULUCF compatible, transparent and verifiable reporting system, which can be updated as new research information becomes available.
- CARBWARE software that can be used for scenario analysis for policy development and projections, investigation of alternative forest management and silvicultural systems, wood product utilisation (including biomass energy) and climate change.
- The expertise obtained through the development of the UNFCCC reporting aspect of CARBWARE will be extended to be used in national accounting (including all land-use activities) by the Environmental Protection Agency (EPA). This has important implications with regard to review, consistency, traceability, transparency and credibility of the national greenhouse gas reporting system as a whole.
- An advisory service to the public on forests and climate change (see www.coford.ie).

## Preliminary results

*Structure of post-1990 forests*

The final approach adopted by CARBWARE will depend on available resources and the underlying structure of national, and particularly post-1990, forests.[1] Pure conifer stands are the most frequent post-1990 forest type (55%), followed by mixed conifers (25%), conifer-broadleaf mixes (14%), mixed broadleaves (4%) and pure broadleaves (2%). Mixed stands represent 40% of all new forests established since 1990. Sitka spruce is the most common dominant in a given stand (54%), followed by larch (15%), while fast growing broadleaves, including alder, ash, birch and sycamore, represent a further 22% of the dominants.

Historically, most afforestation has taken place on peat soils. However, increased plantation establishment on marginal farm lands dominated by mineral soils has resulted in a decline in afforestation on peat soils from 56% in 1990 to 29% in 2003. By 2006, the dominant soil types afforested since 1990 included blanket peats (36%), mineral gleys (31%), basin peats (10%), brown earths (6%), brown/grey brown podsols (5%), with others accounting for the balance.

[1] Sources for forest statistics are the 2006 NFI, Inventory Planning System (FIPS) dataset and a soil and subsoil map, developed by Teagasc, with funding provided by the Forest Service and the Environmental Protection Agency.

*Validation and future improvements to the CARBWARE model*

Validation and refinement of national reporting systems is an important component of the international reporting mechanism. Delivery of strategic research information relating to policy and national reporting obligations is crucial to the development of CARBWARE.

The Sitka spruce cohort sub-model has been tested and validated against experimental data obtained from an age sequence of Sitka spruce stands growing on mineral gley soils (Black et al. 2007, Black 2007). Research data were obtained from a long-term research project (CARBiFOR II) under the CLIMIT programme. Although there was a good correlation between experimental and model data ($p<0.01$, Figure 5A), CARBWARE estimates were systematically underestimated in older stands (Figure 5B). Sensitivity analyses on stand-level growth models used in CARBWARE suggest that the largest degree of uncertainty (ca. 30%) and underestimation in older stands was associated with the estimation of the forest biomass carbon sink. Uncertainty of the biomass sink was affected most by forest management assumptions (i.e. thinning interventions). Underlying management assumptions in CARBWARE adopted the Edwards and Christy (op. cit.) yield tables, which prescribe a thinning intensity of 70% (commonly known as marginal thinning intensity) of the mean annual volume increment on a 5-year cycle,. However, this is not strictly practised in Irish forests, as stands are generally thinned later in the rotation than assumed in the yield tables, and subsequent thinning is less intensive. Recent information from the NFI also suggests that 79% of the national forest estate is currently unthinned, where thinning is a management option (Redmond 2007).

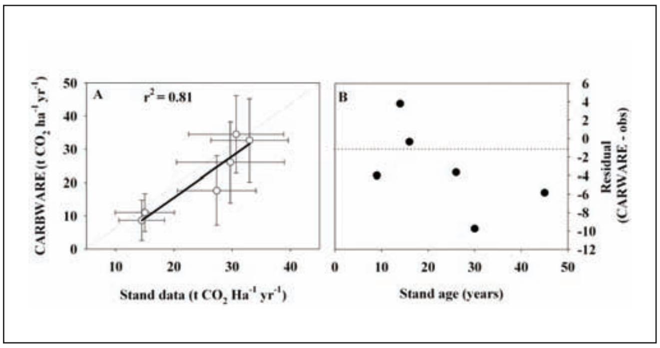


Figure 5: An inter-comparison showing the relationship (A) and differences (B) between experimentally-based stand, and the Sitka spruce sub-model (CARBWARE) estimates of $CO_2$ sequestration rates across a Sitka spruce age sequence.

To date, the lack of detailed national and stand level harvesting and thinning statistics has resulted in the implementation of generalised management scenario assumptions within the growth model. This introduces a large degree of uncertainty and weakens the CARBWARE reporting methodology under IPCC and international reporting guidelines.

It is proposed, therefore, to move from stand-level to single-tree growth modelling in order to accurately predict growth where there are no predefined limits on species mixtures, silvicultural treatments, tree age or productivity. Although is not clear what proportion of the mixed stands are intimate mixes, the specification of the single tree model as distance independent allows for the effect of growth competition to be taken into account regardless of thinning or spatial location of different species or other individuals within a stand. This is achieved by parameterising multiple variables relating to competition, mortality and site-specific factors. The ability to assess competition within a stand is linked to crown variables, which have been captured in the NFI. Single tree models are being developed for five species cohorts, including spruces/fir, pines, larch, slow growing broadleaves (based on oak) and fast growing broadleaves (based on ash). These models will be developed from data housed in the Coillte permanent plot database (Ted Lynch personal communication).

*Simulated $CO_2$ sequestration scenarios*

The extent to which new forests sequester $CO_2$ over the Kyoto commitment period (2008-2012) and beyond will be primarily dependent on the annual afforestation rate, species planted, harvest management and soil type. Applied assumptions regarding afforested areas, soil species breakdown and management scenarios into the future are speculative; and estimates will be refined as new information becomes available and models are improved. Figure 6 shows the predicted sequestration rate of post-1990 forests over the three 5-year contiguous commitment periods, assuming four different afforestation scenarios. Assuming that an afforestation rate of 10,000 ha is maintained, the annual net sequestration is expected to rise from ca. 1.7 M t $CO_2$ in 2006 to 4.5 M t $CO_2$ in 2022. However, the potential sequestration rate may lower (3.6 M t $CO_2$) by 2022 if the afforestation rate declines to 3,000 ha per year. The afforestation rate over the past four years is well below 15,000 ha per year.

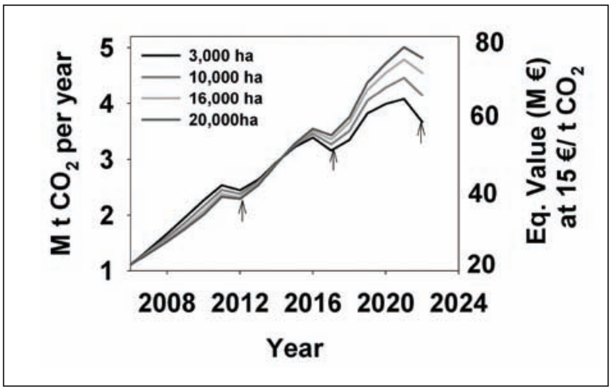


Figure 6: Annual $CO_2$ sequestration rates and its estimated value in post-1990 forests over three contiguous 5-year periods (2008-2012; 2013-2017; 2018-2022 as indicated by arrows), assuming four different afforestation scenarios. Harvest over this period is assumed to follow marginal thinning intensity.

A common feature of the CARBWARE simulation output is the lower initial net sequestration rate for the higher afforestation rate scenario. This is due to the initial loss of $CO_2$ associated with emissions from peat soils. Another feature of the output data is the decrease or 'troughs' in the simulated sequestration rates for any given afforestation scenario (e.g. starting in 2010). This is due to losses associated with thinning and harvest of some stands, particularly the more productive Sitka spruce stands.

*Emission reduction by post-1990 forests*

Assuming a business as usual scenario for national emissions (68.46 M t $CO_2$ in 2004; McGettigan et al. 2006), Ireland's emissions will be 23% above the 1990 assigned amount. This represents an emission excess of 5.46 Mt $CO_2$ per year or 27.3 Mt $CO_2$ above the first commitment period target. The potential emission removal due to afforestation under article 3.3 of the Kyoto Protocol is estimated to be 10 to 13 Mt of $CO_2$ for the first commitment period. Therefore, post-1990 forests can potentially offset the national emission excess by 37 to 47% over the first commitment period.

*Long-term mitigation*

Figure 7 illustrates the long-term $CO_2$ removal from the atmosphere over five rotations based on a CARBWARE model for a thinned Sitka spruce (YC 16) stand with and without harvested wood product storage scenarios. The model transfers stem wood from thinnings to the harvested wood products pool, assumed to be converted to paper or packaging with a mean lifetime of five years (Dewar and Cannell 1992). It was assumed that the lifetimes of wood products from final harvest were equal to the rotation length (Dewar and Cannell 1992). The non-wood product storage scenario assumes the IPCC guidelines, where stored C in harvested timber is immediately lost as $CO_2$. The annual mean equilibrium $CO_2$ storage for the national average Sitka spruce yield class (YC 16) over the long term was estimated to be 8.7 to 10.0 t $CO_2$ $ha^{-1}$ $yr^{-1}$, depending on which harvested wood product storage scenario was included in the model. The equilibrium storage rate for most plantations could range between 4 and 12 t $CO_2$ $ha^{-1}$ $yr^{-1}$ depending on soil type, species, rotation length and management.

It is important to note that the storage capacity of an afforested area is likely to reach a steady state over successive rotations. This implies that the additional sequestration potential of an area is close to zero once the first rotation is complete; mitigation potential is therefore once-off, unless forest management practices over and above the normal practice are implemented. These may include altering thinning strategies, rotation lengths or the introduction of new silvicultural practices, such as shelterwood (continuous cover) silvicultural systems. As it currently stands, such activities can be elected for a given commitment period under Article 3.4 of the Kyoto protocol, but Ireland did not elect them for the first commitment period.

These projections are, however, speculative and subject to a high degree of uncertainty. For example, it is not clear how climate change itself may influence the long-term storage of C in forest plantations. The development of GIS-based productivity maps and climate change risk assessments for different species under the CLIMADAPT project (see Ray 2008, this publication)

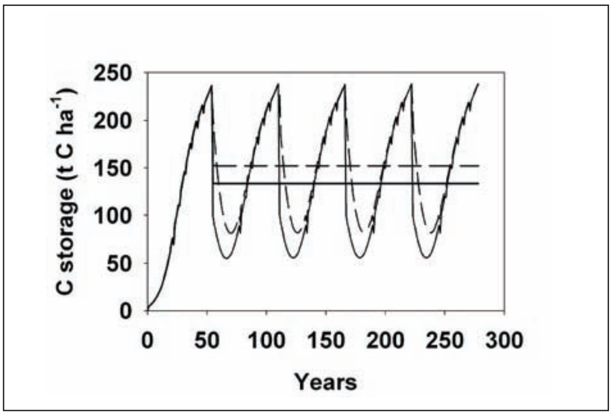


Figure 7: Predicted changes in C storage over five rotations of thinned Sitka spruce (YC16, 2 m spacing on mineral gley soils) plantations, assuming immediate wood C loss at harvest (solid line) or harvested wood product storage (broken line).

will provide the opportunity to predict how forest sinks on the island may be influenced by future climate.

If the objective is to store large amounts of C over the long term, without considering the initial storage, the best options would to be to:

- Plant high productivity class conifer plantations, without carrying out any subsequent thinning. It has been suggested that thinning reduces the total storage in Sitka spruce by 15% (Dewar and Cannell 1992).
- Establish plantations of high yielding broadleaves, such as ash and sycamore.
- Establish plantations on mineral soils.

It is also important to note that the post-1990 afforestation C storage capacity will eventually be neutral if current afforestation rates are not sustained over the next two decades. From a national perspective, it would be important to provide policies and incentives to continue afforestation at rates comparable to those achieved in the 1990s in order to ensure a sustained emission reduction consistent with normal forest management and harvesting levels.

## Acknowledgements

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# Forest soils – a vital carbon reservoir

Kenneth A. Byrne and Ger Kiely

Centre for Hydrology, Micrometeorology and Climate Change, University College Cork

## Abstract

It is now generally accepted that the earth's climate is undergoing change as a result of anthropogenic activity. This is caused by increasing atmospheric concentrations of greenhouse gases, principally carbon dioxide, methane and nitrous oxide. Among the measures being utilised to offset or mitigate greenhouse gas emissions is carbon sequestration in forest ecosystems. Forests are an integral component of the global carbon cycle with 39 and 77% of global C stocks being stored in forest vegetation and soils respectively. Afforestation and forest management activities impact on soil carbon cycling and have the potential to increase or decrease soil carbon stocks. This paper discusses carbon sequestration in forest soils and assesses current and future research in relation to carbon sequestration in Irish forest soils.

## Introduction

Since the industrial revolution there has been a dramatic increase in the atmospheric concentration of carbon dioxide ($CO_2$) and other greenhouse gases (GHGs). The atmospheric concentration of $CO_2$ has risen from 285 ppmv in 1750 to 379 ppmv in 2005 and is increasing at the rate of 1.4 ppmv per year (Forster et al. 2007). Over the same period, atmospheric methane ($CH_4$) concentration has increased from about 700 ppbv to 1774 ppbv but does not appear to be increasing at present (Forster et al. 2007). Similarly, the atmospheric concentration of nitrous oxide ($N_2O$) has increased from about 270 ppbv in 1750 to 319 ppbv in 2005 and is increasing at the rate of approximately 0.84 ppmv per year (Forster et al. 2007). This enrichment of GHGs in the atmosphere is anthropogenically driven, with fossil fuel usage and land-use change being the principal agents for $CO_2$ emissions, while agriculture is the principal source of $CH_4$ and $N_2O$. According to the Intergovernmental Panel on Climate Change (IPCC 2007) '*Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations*'.

There is now widespread evidence of warming of the climate system as illustrated by the following examples (IPCC 2007):

- Eleven of the last twelve years (1995–2006) rank among the 12 warmest in the instrumental record of global surface temperature (since 1850).
- The frequency of heavy precipitation events has increased over most land areas, consistent with warming and observed increases of atmospheric water vapour.
- Mountain glaciers and snow cover have declined on average in both hemispheres. Widespread decreases in glaciers and ice caps have contributed to sea level rise (ice caps do not include contributions from the Greenland and Antarctic Ice Sheets).

Given the prospect of continued increases in atmospheric GHG concentrations, further changes in climate can be expected. The opinion of the IPCC (IPCC 2007) is that '*continued greenhouse gas emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely be larger than those observed during the 20th century*'.

Among the challenges presented by climatic change is the need to understand the processes responsible for net sources and sinks of GHGs. This will lead to more accurate predictions of future atmospheric concentrations of GHGs and improved predictions of the rate and extent of climate change. Such knowledge will also underpin efforts to mitigate and reduce GHG emissions to the atmosphere.

## Soils and the global carbon cycle

Soils are an integral component of the global carbon (C) budget and are estimated to contain 2011 Pg (1 Pg = 1 Gt = 1015 g) of organic C (Table 1). This is about four times the amount of C in vegetation (Table 1) and twice the amount in the atmosphere (Bolin et al. 2000). These pools are large compared to annual fluxes of C between the terrestrial biosphere and the atmosphere. During the 1990s, 6.3 ± 1.3 Pg C per year was emitted to the atmosphere from fossil fuel consumption and cement production, while land-use change led to emissions of 1.6 ± 0.8 Pg C per year (Prentice et al. 2001; Schimel et al. 2001). During the same period, atmospheric C increased at a rate of 3.2 ± 0.1 Pg C per year, ocean uptake was 2.3 ± 0.8 Pg C per year and terrestrial carbon sinks absorbed 2.3 ± 1.3 Pg C per year (Prentice et al. 2001; Schimel et al. 2001). Furthermore, Bolin et al. (2000) estimated that the annual fluxes of $CO_2$ from the atmosphere to land (global net primary productivity) and land to atmosphere (respiration and fire) are of the order of 60 Pg C per year. In addition, small changes in the global soil C pool may have a significant impact on the atmospheric concentration of $CO_2$.

Forests are significant stores of carbon, accounting for 39 and 77% of global C stocks in vegetation and soil respectively (Table 1). Some differences are evident between forest biomes, with boreal forest soils having an average C stock of 344 t C per hectare, compared to 123 t C per hectare in tropical forests. This is due to the slower C turnover time in boreal conditions as a result of the lower temperature and generally less favourable conditions for decomposition in boreal regions.

Human activities have greatly reduced soil C stocks. Various estimates exist of the historic loss of soil C as a result of changes in land use and management including 500 Pg by Wallace (1994), 55 Pg by Schimel (1995) and 78 ± 12 by Lal (1999). Although these estimates are highly uncertain, they do show that soils are an important source of atmospheric $CO_2$. The presence of large soil C stocks in forests suggests that forest soils have the potential to store large quantities of C. Liski et al. (2002) calculated the C budget of soils and trees in the forests of 14 EU countries, plus Norway and Switzerland, from 1950 to 2040 and estimated that the C stock of the soils will increase from 26 Tg per year in 1990 to 43 Tg per year in 2040. Smith et al. (2006) assessed C stock changes in forest soils for the EU25 plus Norway and Switzerland and found that climate change will be a key driver of change in forest soil C, but that changes in age class structure and land-use change are estimated to have greater effects, leading to small losses or increasing soil C stocks.

## The policy context of C sequestration in forest soils

Articles 3.3 and 3.4 of the Kyoto Protocol allow Parties to use C sequestration in forests to meet their GHG emissions reduction commitments. Article 3.3 refers to net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced afforestation, reforestation and deforestation which has taken place since 1990; Article 3.4 refers to additional human-induced activities in the agriculture, land-use change and forestry sectors. The rules for the implementation of the Kyoto Protocol are detailed in the Marrakesh Accords agreed at the Seventh Conference of the Parties (COP 7) at Marrakesh in November 2001. Under this agreement, there is no limit to the

Table 1: Global C stocks in vegetation and top 1 m of soils (from Bolin et al. 2000).

| | | Carbon Stocks (Gt C*) | | |
|---|---|---|---|---|
| Biome | Area ($10^9$ ha) | Vegetation | Soils | Total |
| Tropical forests | 1.76 | 212 | 216 | 428 |
| Temperate forests | 1.04 | 59 | 100 | 159 |
| Boreal forests | 1.37 | 88 | 471 | 559 |
| Tropical savannas | 2.25 | 66 | 264 | 330 |
| Temperate grasslands | 1.25 | 9 | 295 | 304 |
| Deserts and semideserts | 4.55 | 8 | 191 | 199 |
| Tundra | 0.95 | 6 | 121 | 127 |
| Wetlands | 0.35 | 15 | 225 | 240 |
| Croplands | 1.60 | 3 | 128 | 131 |
| Total | 151.20 | 466 | 2011 | 2477 |

*1 Gt = 1 x $10^9$ tonnes

amount of credits a Party may accrue from Article 3.3, while limits have been placed on the amount of credits which can be obtained from forest management under Article 3.4; for Ireland this limit was set at 50,000 t C $yr^{-1}$ during the first commitment period, i.e. 2008-2012 (Ireland subsequently elected not to use Article 3.4). Under Article 3.3, all developed countries are required to account for C stock changes in above-ground biomass, below-ground biomass, litter, dead wood and soil organic carbon. Guidance on the preparation of GHG inventories which meet the requirements of the Marrakesh Accords is provided by the Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry (Penman et al. 2003). However, there is a need for nationally specific data to ensure that such inventories are representative of national circumstances, and to reduce uncertainty and facilitate reporting at higher tiers.

## Factors influencing soil C stocks

The soil C stock is determined by the balance between C input through litterfall and root turnover and C release during organic matter decomposition. The rate of turnover of soil C depends on the chemical composition of organic matter (labile or stable), site conditions (climate) and soil properties (soil moisture, pH, nutrient content and clay content). Labile organic matter will decompose more quickly (~ 1 year) than stable organic matter (tens of years). Climate is an important factor in soil formation (Jenny 1941) and soil properties such as soil C are in dynamic equilibrium with climate, especially rainfall and temperature. In general, the soil C stock is larger in regions with high rainfall and cool temperatures than in those with low rainfall and high temperatures. Excess soil moisture retards organic matter decomposition and therefore promotes soil C accumulation (as in peatlands) whereas in Mediterranean forests summer droughts inhibit decomposition. Increasing acidity will retard decomposition, while increased nutrient availability will promote decomposition. Clay minerals provide reactive surfaces where organic matter is absorbed, and an intimate bond is formed resulting in the stabilisation of soil C (Torn et al. 1997)

Afforestation of agricultural land has the potential to increase soil C stocks, particularly when such land has depleted soil C reserves as a result of cultivation. Accumulation will occur until a new equilibrium is reached between C inputs and C losses. In forests, the initial accumulation of C takes place in the forest floor, where the depth and chemical properties vary with tree species (Vesterdal and Rauland-Rasmussen 1998). Post and Kwon (2000) reviewed literature where changes in soil C are reported following land-use change from cropland to forest. The average rate of soil C sequestration across several different climatic zones was 0.3 t C $ha^{-1}$ $yr^{-1}$ (range 0 – 3 t C $ha^{-1}$ $yr^{-1}$). They found large variation in the rate of soil C accumulation and attributed this to the productivity of the vegetation, physical and biological conditions in the soil and the past history of soil C inputs and physical disturbance. In a similar analysis, Guo and Gifford (2002) found that, on average, afforestation increases soil C by 18% over a variable number of years although some soils may lose C or undergo no change.

Using a chronosequence approach, Vesterdal et al. (2002) investigated the effect of afforestation of former arable land on soil C stocks. They found that while oak (*Quercus robur*) and Norway spruce (*Picea abies*) sequestered 2 t C $ha^{-1}$ and 9 t C $ha^{-1}$ respectively over 29 years there was relatively little change in soil C stocks. Zerva et al. (2005) found that following the establishment of Sitka spruce (*Picea sitchensis*) on peaty gley soils in north east England there was a decline in soil C stocks during the first rotation but that there was a restoration of stocks during the second rotation (Figure 1).

Soil C losses may occur following afforestation when C inputs from the growing trees are insufficient to compensate for losses of C due to organic matter decomposition. In a review of paired sites studies to assess the impact of grassland afforestation on soil C stocks in New Zealand, Davis and Condron (2002) found that in the short term afforestation reduces upper mineral soil (0-10 cm layer) C stocks by about

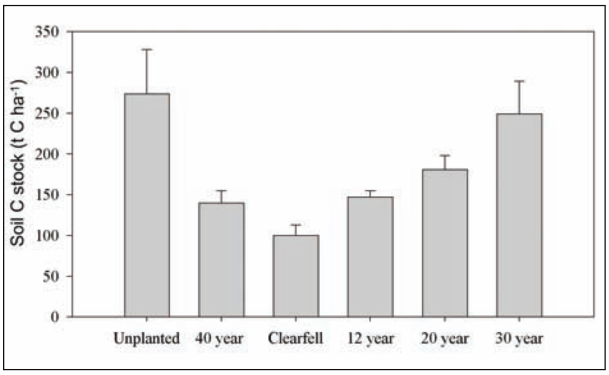


Figure 1: Soil C stocks in a Sitka spruce chronosequence on peaty gley soils in north east England (from Zerva et al. 2005). The vertical bars represent the standard error of the mean.

4.5 t C $ha^{-1}$ or 9.5%. Beyond age 20, soil C stocks were restored to pre-afforestation levels while C accumulation in the forest appeared to compensate for any reduction in soil C stocks following afforestation.

Although vegetation is a major factor in soil formation there is no clear understanding of the effect of tree species on soil C stocks across different soil types. Vesterdal et al. (in press) studied a range of broadleaf species and found that while there were differences in soil and litter layer C sequestration rates, there was little difference between species after 30 years. While the rate of C accumulation in the litter layer differs between species, this C is labile and an increase in more recalcitrant soil C may be preferable. This is primarily derived from below-ground biomass, but in a recent review Jandl et al. (2007) found little evidence for this.

Forest management practices impact on C cycling and therefore have the potential to influence soil C stocks. This includes activities such as drainage and site cultivation, thinning and clearfelling, and rotation length.

Site preparation practices such as drainage and cultivation promote aeration and thereby increase organic matter decomposition and losses of soil C. This is especially so in peat soils which have very high C stocks, predominantly as a result of the high water table, and drainage can lead to a loss of soil C. However, these losses may be compensated by litter layer accumulation and below-ground biomass allocation. Studies have reported decreases and increases of soil C following drainage (e.g. Braekke and Finer 1991; Minkkinen and Laine 1998). If soil C losses occur they are usually compensated by C sequestration in vegetation (Hargreaves et al. 2003; Minkkinen et al. 2002). In a study in a boreal mixed-wood forest, Mallik and Hu (1997) found that site preparation reduced soil organic matter content significantly. The reduction in soil C depends on the extent of soil disturbance (Mallik and Hu 1997) and also on the rate of C input to the soil by the growing forest.

The objective of thinning is to shift the distribution of growth to larger, more valuable trees. Following thinning the forest litter layer can become warmer and wetter leading to increased decomposition rates. In addition, litterfall is reduced and soil C stocks may diminish. However, this may be compensated for by inputs of harvesting residues. While forest floor C stocks are known to reduce with increasing thinning intensity (Vesterdal et al. 1995), changes in soil C stocks have not been reported.

Clearfelling can have significant impacts on soil C stocks. Conditions for organic matter decomposition are more favourable after harvesting and litterfall and below-ground biomass allocation cease. Harvest residues may compensate for litter and soil C losses and the growing forest will provide new inputs of C. In a review of harvesting techniques, Johnson and Curtis (2001) found that harvesting had little or no effect on soil C but that soil C stock were increased following sawlog harvesting and attributed this to inputs of harvest residues to the soil.

Longer rotations have been proposed as a means of enhancing C sequestration. While old growth forests have high C stocks, the C sink potential (or annual C sequestration rate) is greatest in young plantations. However productivity is reduced in mature forest stands with a consequent reduction in litterfall and this may lead to a levelling of soil C stocks (Kaipainen et al. 2004). While at the landscape or regional level adoption of longer rotations may increase C stocks, it would increase pressure on other forests (in order to maintain timber supply). In conclusion, while longer rotations may increase C stocks at stand level, their impact would need to be considered at regional and national level.

Fertilisation leads to increases in productivity when the nutrients applied are limiting. Canary et al. (2000) found that N fertilisation increased soil C in second growth Douglas fir (*Pseudotsuga menziesii*) but cautioned against using results of site-specific studies to make regional level recommendations. While P fertilisation will also increase productivity on nutrient limited sites, we are unaware of any studies that investigate changes in soil C stocks.

Disturbances disrupt C dynamics and can lead to C losses. Fires are a common phenomenon in boreal and Mediterranean forests, the occurrence of which can be delayed by fire suppression measures. However, the build up of biomass and organic matter can lead to massive C release when fire does eventually occur. Where fire occurs there can be losses of biomass and organic matter (litter layer and soil). There will also be losses of N with consequences for future productivity and C sequestration potential. Insect infestation reduces productivity (Straw et al. 2000) which will reduce litterfall and soil C accumulation. Windthrow can increase the amount of wood debris on the forest floor and contribute to organic matter accumulation.

If uprooting of trees occurs it will damage soil structure and soil organic matter may be more accessible to decomposers. For example, two years after a windthrow in European Russia, Knohl et al. (2002) found that over a three month period the ecosystem lost 2 t C $ha^{-1}$ to the atmosphere.

## Irish forests – state of knowledge and research needs

The study by Kilbride et al. (1999) was the first attempt to estimate biomass C stocks and sequestration in Irish forests. The foundation for a C accounting system was developed by Gallagher et al. (2004) and this has been incorporated in CARBWARE (Black and Gallagher 2007) which is the national forest C accounting system. This system has been developed in light of the Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry (Penman et al. 2003) and as the results of national research become available. Although there were studies of C cycling in peatland forests (Byrne and Farrell 2005; Byrne et al. 2001) our understanding of C cycling in Irish forests remained limited until the advent of the COFORD-funded CARBiFOR project (Farrell and Black 2006). This study used a chronosequence approach to study C cycling in Sitka spruce afforestation on gley soils. In addition to providing data on C stock and turnover in biomass (Black et al. 2004; Tobin et al. 2007; Tobin et al. 2006; Tobin and Nieuwenhuis 2007) the project also provided insights into soil C stocks (Green 2006) and soil $CO_2$ emissions in Sitka spruce forests (Saiz et al. 2006). The rate of C sequestration in forest soils at national level has been estimated by Byrne and Milne (2006) using a model developed for forests in the United Kingdom and suggests that forest soils are a net sink for 0.5 M t C $yr^{-1}$. Further advances will be made with the recently commenced COFORD-funded ForestSoilC and CARBiFOR II projects. The paired plot approach (Scott et al. 1999) is being used to assess the impact of afforestation on soil C stocks. The sites will be chosen from the recently completed National Forest Inventory. In addition, the chronosequence approach will be used to determine C emission factors for afforested peat soils and soil C turnover in broadleaf forests. This research will provide information that will be input to the CARBWARE C accounting system and will advance our understanding of C stocks and sequestration in Irish forests. In addition to supporting national and international policy commitments, this will strengthen the environmental sustainability of Irish forestry.

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# The impact of climate change on forests in Ireland and some options for adaptation

Duncan Ray[1], Georgios Xenakis[1], Tido Semmler[2] and Kevin Black[3]

[1] Forest Research, Roslin

[2] Met Éireann

[3] FERS Ltd.

## Abstract

The scientific evidence for climate change caused by the emissions of greenhouse gases into the earth's atmosphere is increasing. A new set of modelled climate projections for Ireland has been downscaled in a regional climate model (RCM) and tested by the Community Climate Change Consortium for Ireland (C4I). The RCM climate simulations provide more detail on the likely changes in Ireland's climate throughout this century. In this paper we examine projections from the medium high (A2) scenario in relation to climatic indices important for forestry, and discuss the impacts and evaluate adaptation options for species choice and forest management.

The change in Ireland's climate in terms of warmth and climatic droughtiness, which are both important for tree growth and survival, has been predicted from C4I data. The spatial and temporal changes in the mean climate indicate increasing warmth and droughtiness in the south and east of Ireland. The decadal frequency of extreme climatic events will increase. Drought frequency is predicted to increase to 3-4 droughts per decade over large parts of central and southern Ireland by 2050, increasing to more than 7 droughts per decade towards the end of the century.

Drought sensitive species such as Sitka spruce and beech are very likely to become less well suited on certain site types in the south and east of Ireland. Irish forestry must therefore adapt to climate change. This involves making changes to species, provenance selection, and silviculture. Decision support tools are urgently required to guide strategic policy, for example to guide woodland grant incentives to maintain a robust and sustainable forest policy response to climate change. Tools are also required to support the operational response, for example to identify potential site and climate related problems, and to identify well-adapted species, provenance and silvicultural systems. Current work within the CLIMIT programme will provide these tools in the COFORD-funded project CLIMADAPT.

## Introduction

The concentration of $CO_2$ in the atmosphere has increased to a level unprecedented in over 800,000 years (Brook 2008). Until the beginning of the industrial revolution in Britain and Europe, the concentration of $CO_2$ in the atmosphere had been fairly constant over a period of a thousand years. $CO_2$ concentrations have increased from about 280 ppm in 1800 to about 380 ppm now (Anon 2007).

The increased concentration of $CO_2$ in the atmosphere has caused a global increase in temperature (Anon 2007; Hulme et al. 2002). For example, the average temperature of Scotland increased by 0.5°C between 1914 and 2004, with a greater increase in the south than in the north (Barnett et al. 2006). Data for Northern Ireland (Arkell et al. 2007) indicate fluctuating annual mean temperatures (Armagh Observatory), but with a general 0.5°C increase between 1854 and 2004.

In response to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) (Anon 2007), the Community Climate Change Consortium for Ireland (C4I) reported a 0.7°C increase in temperature between 1900 and 2004 (C4I 2007). The report describes a current and rapid period of warming which began about 1980. This has caused 10 of the 15 warmest years in Ireland this century to occur since 1990; the last decade was the warmest on record.

The IPCC has published predictions of $CO_2$ concentrations for the 21st century based on different projected human population and fossil fuel use scenarios. The models predict that the lowest possible stabilisation level of $CO_2$ by 2100 is approximately 450 ppm, but if fossil fuels continue to used at the current rate (business as usual), the concentration of $CO_2$ in the atmosphere could rise to as high as 650 ppm. These projections form the basis of a set of future $CO_2$ emissions scenarios published by the IPCC (Anon 2000b). Examples include a High emissions scenario referenced as A1FI (fossil fuel intensive), Medium-High emissions A2, Medium-Low B1 and Low emissions A1T, on which the future predictions of climate change have been based within general circulation models (GCM).

GCMs include coupled ocean and atmosphere circulation components (Met Office 2007) to predict how changes in greenhouse gas concentrations will affect the climate of the earth. GCMs are designed to predict changes in the climate at the global scale, and so operate at a fairly coarse resolution (typically 2.5° or 300 km), making it difficult to assess impacts at a regional level. To resolve this problem for Ireland, a dynamical downscaling method was used. C4I has applied this technique in a regional climate model (RCM) developed by the Rossby Centre (Sweden) and validated using backcasting techniques (McGrath et al. 2005). Using the RCM, Met Éireann has now produced gridded (15 km resolution), daily simulations of a range of meteorological variables for both the A2 Medium-High emissions scenario, and the B1 Medium-Low emissions scenario, forward into the 21st century. These data are being developed into a set of climate variables for a decision support system, similar to Ecological Site Classification (ESC) (Pyatt et al. 2001; Pyatt et al. 2003; Ray 2001; Ray and Broome 2003) to examine how climate change will impact on tree species suitability (Broadmeadow and Ray 2005; Broadmeadow et al. 2005).

Here we concentrate on the main changes predicted for the climate of Ireland, how these changes might affect forests and woodlands, and how foresters should adapt management to reduce the impact of climate change.

## Climate change in Ireland

Increased mean temperatures are projected for the whole year in the future climate of Ireland, although the largest anomaly is projected in January, particularly for the midlands where an increase of 1.2°C is expected. Warmer temperatures will cause a significant increase in accumulated temperature across the country. Accumulated temperature is an index of climatic warmth (Pyatt et al. 2001), with a threshold set at 5°C, above which both plant respiration and growth begin (Grace et al. 2002). In Ireland the mean increase in accumulated temperature above 5°C calculated between the months of March and October (inclusive) is projected to be about 200-300 day.degrees (15% increase). From the daily simulations for the period 1961-2000 and for the period 2021-2080, the annual moisture deficits have been calculated, following the method of Pyatt et al. (2001). The projections of moisture deficit show large increases of 40-60 mm in the south and east of the country, when comparing the climatic 30-year mean between the baseline period and the 30-year period at the end of this century (Figure 1). This is partly due to warmer summers and to a shift in the seasonality of rainfall, with less in summer months (up to 15% decrease) in parts of Ireland and more in winter months (20% increase).

Over the four decades 1961-2000 the frequency of drought in the south of Ireland has increased from 2 years per decade to nearly 4 years per decade. Projections for future decades suggest a further increase in the frequency of dry summers to 5 years per decade in 2050, and 8 years per decade by 2080. By the end of this century the south and east of Ireland could be subject to moisture deficits of 200 mm or more, in 8 years out of 10, similar to the hot, dry summer of 2003.

A warmer atmosphere can hold more moisture, and this is expected to cause an increase in the global average water vapour pressure. The frequency and intensity of rainfall has increased over recent years (C4I 2007), and studies predict that flooding will occur more frequently in Ireland, particularly during the winter months (Wang et al. 2006). The wind climate is also projected to change but the degree of change is less clear. However, the intensity and frequency of Atlantic depressions influencing the weather pattern and climate of Ireland is predicted to increase (Semmler et al. in review), with the

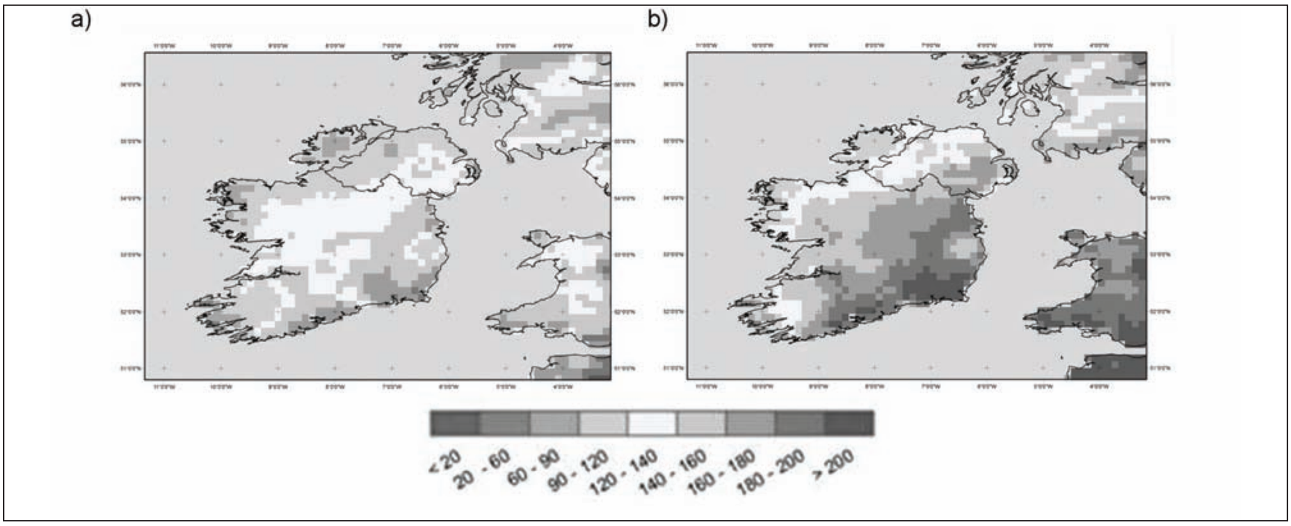


Figure 1: Average moisture deficit (mm) for two 30-year climate periods, a) calculated for the baseline period 1961-1990, and b) calculated for the period 2051-2080 for the Medium-High emissions scenario.

frequency of very intense storms increasing by a factor of two by the end of the century.

## Impact on forests and woodlands

*Productivity*

Where other factors important for growth are not limiting, the warmer climatic conditions will tend to increase productivity. Forest productivity has been increasing across Europe for some time. Estimates suggest that a general yield class (YC) increase of 2-4 $m^3$ $ha^{-1}$ $yr^{-1}$ results from an increase in mean temperature of 1°C (Cannell 2002). Although some of the increased productivity is thought to result from improved silviculture and genetic improvement (Worrell and Malcolm 1990), the main cause is now thought to be nitrogen fertilisation from atmospheric pollution (Goodale et al. 1998; Magnani et al. 2007) in combination with a warming climate and higher rates of decomposition of soil organic matter.

*Species choice*

The increasing frequency of dry summers, where the average summer moisture deficit is greater than 200 mm will severely affect a number of species. In particular, Sitka spruce (*Picea sitchensis*), Norway spruce (*Picea abies*), Japanese larch (*Larix kaempferi*) and beech (*Fagus sylvatica*) are likely to become less suitable in a drier climate (Broadmeadow and Ray 2005). In addition, downy birch (*Betula pubescens*), common alder (*Alnus glutinosa*), pedunculate oak (*Quercus robur*), and ash (*Fraxinus excelsior*) will become less suitable on shallow freely draining soils (Pyatt et al. 2001) in the drier areas of the south and east of Ireland.

*Windthrow*

Endemic windthrow is common on forest sites with high winter water tables caused by imperfectly or poorly drained soils. About 50% of the area of Ireland is characterised by soils with high winter water tables. However, the distribution of the area of winter waterlogged soils under forest is skewed (compared to the national coverage), with almost 70% of forest on soils with a high winter water table (Figure 2) (Redmond in press). In waterlogged soil, oxygen is quickly depleted, leading to anaerobic conditions (characterised by gleying) which prevents plant root respiration, causing root death and a reduction in tree stability (Ray and Nicoll 1998). The predicted change in the seasonality of rainfall, with a 20% increase in the winter months is likely to exacerbate windthrow caused by shallow rooting, and there is therefore an increased likelihood of more endemic windthrow on wet soils, and, coupled with the predicted increase in frequency of intense storms, an increase in the likelihood of catastrophic windthrow (Nisbet 2002).

*Pests*

The warmer climate and changing rainfall distribution will have a profound effect on the ecology of tree pests. Insects will respond to the warmer climate by increasing their rate of development and the number of generations per year. Milder winters will allow larger populations to over-winter. Outbreaks of the green spruce aphid (*Elatobium abietinum*) have caused severe defoliation of spruce plantations in Ireland, severely reducing productivity (Black et al. 2007). The aphid population is vulnerable to low winter temperatures, so the increasing probability of milder winters seems certain to lead to more frequent outbreaks (Day et al. 1998). Drought stressed trees attacked by aphids are also more susceptible to bark beetle attack (Wainhouse pers. comm.). Pine weevil (*Hylobius abietis*) is a serious pest of both pine and spruce plantations, particularly in areas where fell-reforest systems are used. The life cycle on spruce is semi-voltine, with the consequence that adults can emerge from stumps in two or more consecutive years (Wainhouse pers. comm.). Newly planted trees are therefore vulnerable to attack for several years. A warmer climate will reduce the life-cycle period of pine weevil, particularly shortening the juvenile stage, thus driving greater synchrony of emergence. This will provide some relief in the reduction of the current 5-year fallow period following felling, adopted in parts of Britain, to a shorter period (Wainhouse pers. comm.).

*Pathogens*

Red band needle blight caused by the fungus *Dothistroma septosporum* is currently expanding its range across Europe. The disease affects many species of pine, but Monterey (*Pinus radiata*), Corsican (*Pinus nigra* ssp. *Laricio*), and lodgepole (*Pinus contorta*) pines are particularly susceptible. The disease can also transfer to other species, including European larch (*Larix decidua*), Douglas fir (*Pseudotsuga menziesii*) and Norway and Sitka spruce (*Picea abies* and *P. sitchensis*). The fungus requires high humidity and warm spring temperatures (12-18°C) (Brown et al. 2003). Currently, on Corsican pine in eastern England, the pathogen causes the premature loss of needles, severely reducing the productivity of affected trees; continued fungal attack increases tree mortality (Green pers. comm.). However, the predicted warmer and drier spring weather in Ireland may not provide ideal conditions for the spread of this pathogen.

Root pathogens such as *Phytophthora* species are increasing in Europe. They are generally associated with mild winters, warm summers and waterlogged soils (Webber pers. comm.). *Phytophthora alni* affects alder and infects trees during flooding events, and is more prevalent in warmer water.

A number of latent pathogens manifest themselves in drought-stressed trees, such as sooty bark disease (*Cryptostroma corticale*) in sycamore. The pathogen remains dormant in the tree, and is triggered into growth by extreme hot and dry summer weather (Green pers. comm.).

*Wood quality*

The Irish climate is ideal for growing Sitka spruce, but increasing productivity usually results in a slightly lower wood density. Selection of material (provenance) and tree breeding afford the opportunity to improve wood quality. A warmer climate and increased $CO_2$ concentrations will stimulate an increase in the production of early wood in Sitka spruce which has the effect of reducing overall strength. In contrast, pines, larches and Douglas fir can grow faster without corresponding reductions in wood density.

Wood quality in broadleaf species varies in response to increased growth in a warmer climate. Ring porous species such as ash, elm and oak produce harder and stronger wood when grown fast. Diffuse porous species such as birch and sycamore do not respond in this way. Beech and chestnut are intermediate in response.

## Options for adaptation

*Species choice*

It is important to ensure that tree species planted now will be suited to changing biophysical site conditions. In particular, it is important to select material with similar ecological, site and climatic requirements to what is predicted during the rotation (Broadmeadow et al. 2005). Two periods are particularly critical: tree establishment and the mature phase prior to harvesting. During establishment seedlings must secure a robust root system for acquiring water and nutrients for growth. This process may be disrupted by waterlogging and/or drought, leading to tree mortality. In mature stands, there is intense competition for resources, including water. In both circumstances, predictions of an increased fluctuation of the water table between seasons provides a greater risk of drought stress, leading to mortality, pest and disease attack, and reduced wood quality and value. On sites with a seasonally fluctuating water table it is important to ensure that species can tolerate the changes.

The predicted warmer and drier climate may offer the possibility of extending the range of species to those less well represented in Ireland. The climate will improve for southern beech 'rauli' (*Nothofagus nervosa*) and 'roble' (*Nothofagus obliqua*), Monterey pine, maritime pine (*Pinus pinaster*), walnut (*Juglans regia* and *Juglans nigra*) (Anon 2000a), and for more southerly provenances of conifers from the Pacific North West (Thompson pers. comm.).

### *Silviculture*

Spreading risk is central to the notion of good management to meet particular objectives in an unknown or uncertain future. Effective silvicultural systems should spread risk by considering mixed species and mixed age structure stands. Transformation to continuous cover forest management is recommended, taking into account changes in the wind climate (Mason and Kerr 2004). Droughty conditions are predicted to increase in the south and east. Fortunately this part of Ireland has a greater proportion of freely draining soils, in a relatively sheltered climate. The opportunity for continuous cover systems would therefore appear better in the south and east than in the midlands and west of Ireland. Where continuous cover management is not suitable because of wind exposure, the option of mixing species (and provenance) in single aged stands should be considered (Broadmeadow and Ray 2005).

It is important to consider the genetic diversity of material planted in forests and woodlands (Hubert and Cottrell 2007). A wider genetic base will maintain a level of adaptability within a population such that the species may produce viable progeny in the future climate. A bigger gene pool in the population will help the species maintain broader ecological amplitude to respond successfully to changing biophysical conditions.

The recent National Forest Inventory (NFI 2007), shows that a large proportion of Irish woodlands are privately-owned conifer stands. The small and fragmented nature of this private woodland resource presents a challenge to silviculture and management. The challenge is partly caused by the economic viability of managing small stands, but it is also due to a lack of silvicultural knowledge among private forest owners. While foresters are well trained in methods of ground preparation and establishment, they are less so in the timing of interventions to maintain well managed stands. Key issues to be addressed include assessing the risks of late or reduced thinning in forests located on soils with impeded drainage, with a high windthrow risk, against not thinning. It has been estimated that of the woodlands where thinning is an option 79% have not been thinned (Redmond in press).

### *Stability*

The projected changes in the wind climate are the least certain. However, because of the skewed wind speed frequency distribution, small changes in the mean wind speed may have important consequences for the frequency of extreme events (Quine and Gardiner 2002). Ireland's forest estate is unevenly distributed across soil types and occupies a relatively greater proportion of wet and peaty soils than the national average. On wetter soils with restricted drainage and seasonally fluctuating water tables (Figure 2), late thinning can exacerbate windthrow. In the future climate it may be necessary to intervene earlier and more frequently to maintain a more gradual canopy transition in the more variable wind climate, or make more use of a self-thinning crop. On soils with fluctuating water tables, stands are at moderate risk from wind damage, and it is on such sites that forest management has a major role to play.

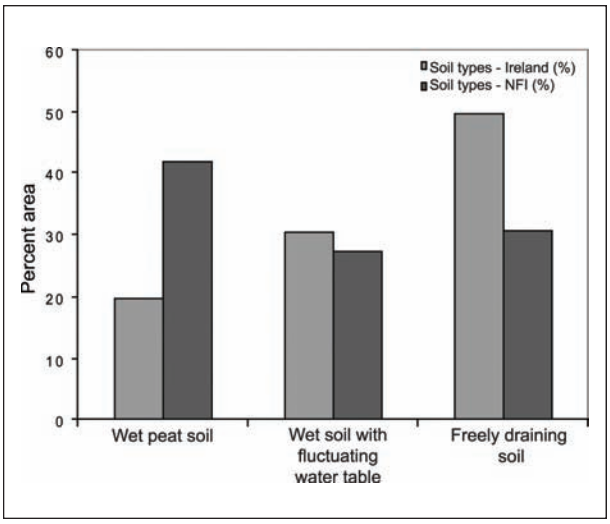


Figure 2: Soils reclassified into wet peat, wet fluctuating water table, and freely draining soils from a) the National Soil Map of Ireland (Teagasc), and b) the National Forest Inventory (Forest Service).

## Decision support

A new programme of research into the carbon sequestration, mitigation and adaptation of forests (CLI-MIT) funded by COFORD is developing carbon accounting models for reporting purposes under the UN Climate Change Convention and the Kyoto Protocol. Within the programme the CLIMADAPT project is designed to deliver a decision support tool to guide sustainable strategic and operational forest planning in the context of climate change. The tool, which will be web-based, will provide guidance in relation to species choice for stands in the current climate and for the IPCC A2 (Medium-High) and B1 (Medium-Low) emissions scenarios.

## Conclusions

Ireland's climate is set to change considerably over the coming century. Predictions are for a warmer climate with a 15% increase in accumulated temperature driving increased productivity for most species, where other resources are not limiting. Increases in productivity of more than 2 $m^3 ha^{-1} yr^{-1}$ are likely on many forest sites.

The future climate will be drier in the summer and wetter in the winter, with more frequent summer drought in the south and east. More thought will be required in relation to species choice on predicted droughty sites, particularly where an increase in the amplitude of fluctuations in water table depth is likely. There are possibilities for extending the range of productive species and provenances planted, particularly from the more southerly latitudes.

Storm frequency and power will increase through the century. Adapting silviculture and management to take account of a windier climate will be a major challenge, particularly in relation to thinning and its timing. On free-draining soils and sheltered sites the options for transformation to continuous cover systems should be considered. Such systems can be more carbon efficient, and will tend to attenuate local changes in temperature and water regimes that would otherwise occur following a clearfelling system.

Tools to provide guidance on species choice are being developed (e.g. CLIMADAPT), and will provide the first decision support tool for future climates. Training in the use of such tools is necessary to guide climate change adaptation strategies for Irish forests.

## Acknowledgements

We are grateful to Met Éireann and C4I for climate data used in this study. The CLIMADAPT project is funded by COFORD.

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# Climate change and energy policy – an economic perspective

John Fitzgerald
Economic and Social Research Institute

**Keynote Address**

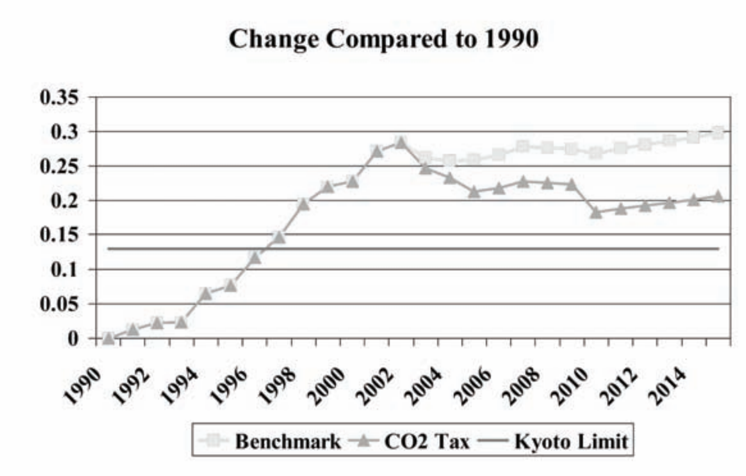
## *Background*

- International Agreements
- Ireland's problem
- Objective - least cost solution
- Policy
  - Fossil fuel emissions - financial instruments
  - Agriculture
  - Forestry
  - Research

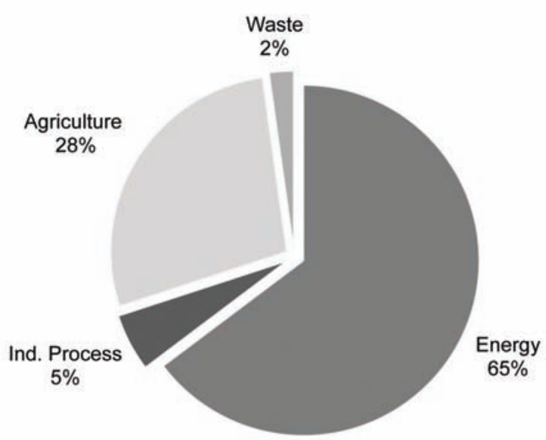
## *International Agreements*

- Problem getting agreement
- Very long time scale for solution
- Need world-wide buy in
- Kyoto - limited coverage and objectives
- Post-Kyoto?
- 'Burden sharing' - is it feasible?
- Alternatives?

## Greenhouse gas




## Emissions - Gross, 2000




## Ireland's Task

- A lot to do, little done
- Want a least cost fair solution
- Be good!
- Emissions trading - EU
- Carbon tax - an essential element
    - affects some sectors - special treatment
    - affects some people - special treatment
- Other instruments

## Implementing Policy

- Ideally:
  - one objective - one policy instrument
- Complexity is costly
  - costly for regulators
  - costly for firms
  - cost of running a good scheme can kill it
- EU Policy Incoherent:
  4 multiple policies for one objective

## Targets as Policy Instrument?

- Targets on:
  - emissions reduction, energy efficiency, biofuels, renewables, etc.
- Legislative targets with no instruments
- Penalties? Pay to EU or to Ireland?
- Key to implementation is instruments

## Least Cost Solution

- Let the market decide
- Fiscal instruments
  - Emissions trading
  - Taxes
  - Subsidies
- Other mechanisms
  - Standards
- Research
  - Market driven or top down?

## *Emissions Trading in Practice*

- Permits allocated for free
  - can be sold - an asset for companies
- Sectors competing on world market
  - output price can not rise - Aughinish
  - free permits may allow plant to survive
- For electricity and cement
  - limited non-EU competition
  - price rises by cost of permits?
  - permits given for free
  - potential windfall gains for shareholders

## *Other Effects of EU Scheme*

- Uncertain price
  - costly for investment and research
- Transactions costs
  - every firm must trade
  - who runs the ‘market’ and for how much?
  - auditing of every firm
- Competition effects - negative
  - capital subsidy to polluters

## *Distributional Consequences*

- Between EU member states
- Within Ireland between
  - consumers and producers
  - rich and poor households
  - different sectors
- Allocation of emission rights determines distributional outcomes
  - auctioned or grandparented?
- Alternative - a common price

## EU - Reforms Needed

- Must auction all permits
- Continued grandparenting
  - bad for competitiveness (anti-Lisbon)
  - bad for competition
  - bad for income distribution
  - use it or lose it and multiple allocations bad
- Preferably trading should apply to all sectors (or else a carbon tax)
  - exemptions for small number of sectors

## Renewables Policy

- Why should there be a policy?
- Renewables encompassed by:
  - global warming policy
  - security of supply policy
- Multiple overlapping policies and instruments leads to:
  - inefficiency - high transations costs
  - loss of competitiveness
- EU and UK policy

## Policy on Transport

- Carbon Tax - small initial effect
- Congestion key environmental issue
  - urban public transport
  - congestion charging
  - emissions reduction a by-product
- EU level crucial
  - standards for fuel efficiency
  - huge market - producers can react
  - long lead in time on R&D

## Housing Efficiency

- Stock to rise by 30% over decade
- Standards for new building
  - more effective than in any other country
- Enforcement?
- Energy efficiency in existing stock
  - price - incentive
  - takes time
  - R&D

## Agriculture

- Agriculture
  - a role to play in a least cost solution
  - needs more consideration 30% of emissions
- Teagasc - decoupling
  - emissions reduction - higher income?
- Consistent approach to land use
- Taking account of externalities

## Forestry

- Time horizon
- Importance as a sink
- Consistency with policy on agriculture
- Land use
  - shows up conflicting policies
- Problems of risk
  - risks for society
  - risks for promoters
  - risks for farmers

## Biomass

- Biofuels enemy of biomass
- Biomass for heating
- Biomass for electricity?
- How high will price go?

## Research

- Research is key to future emissions reduction
  - technology the solution: when and how?
- US ‘Stalinist’ model
  - top down
  - taxpayer pays - costly
- If environment is priced
  - price signals potential profit
  - research driven by potential profit

## Conclusions

- Governments are not infallible
- Use fiscal instruments
- Long-term R&D essential
- Forestry important as a sink and as a fuel

# Ireland's national climate change strategy 2007-2012

Owen Ryan
Department of the Environment

## *Global problem/global solution*

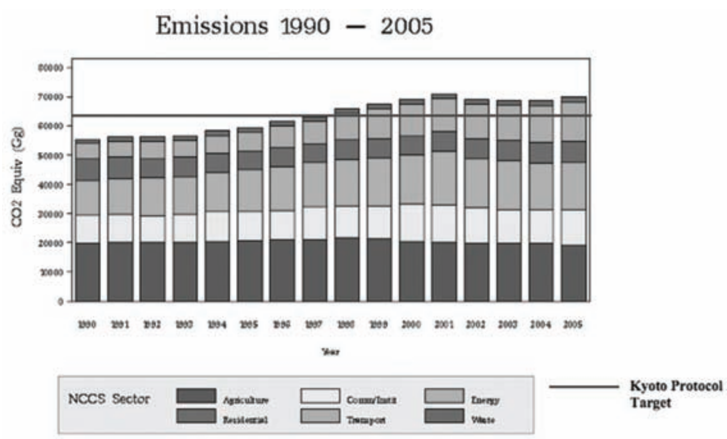
- IPCC Fourth Assessment Report confirms global **scientific** consensus that climate change is happening and is directly related to man-made greenhouse gas emissions.
- **Economic** consensus (Stern Report) that the costs of inaction will greatly exceed the costs of action.
- **Political** momentum now for action.

## *Climate Change Agenda*

Key elements:

- International agenda:
  - UNFCCC (1992);
  - Kyoto Protocol (1997);
  - IPCC – 4th scientific assessment report (2007).
- EU agenda:
  - European Cimate Change Programme.
- National agenda:
  - National Climate Change Strategy.

## *Emission Trends*




## *Policy Framework*

- *National Climate Change Strategy* (2000).
- ICF/Byrne Ó Cléirigh Projections March 2006.
- Review of NCCS: *Ireland's Pathway to Kyoto Compliance*, July 2006.
- Public consultation: Aug-Sept 2006.
- Energy White Paper, Bioenergy Action Plan, National Development Plan.
- EU commitments on 2020 targets.
- *National Climate Change Strategy 2007-2012.*

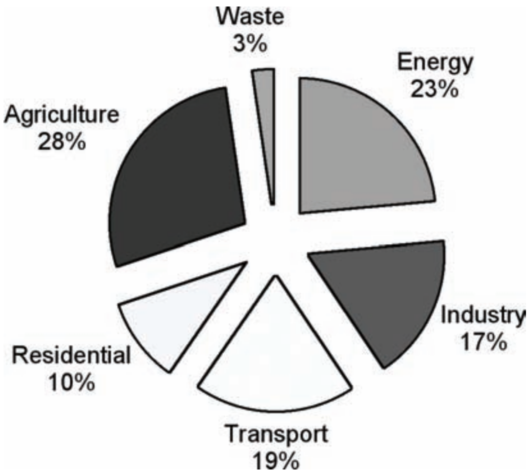
## *Objectives of Strategy*

- Objectives:
  - to show how Ireland will meet its Kyoto Protocol commitment in the 2008-2012 period, and
  - to prepare for more stringent emission reduction requirements post-2012.
- Framework to achieve Kyoto target:
  - variety of domestic measures to reduce emissions throughout the economy,
  - supplemented, as necessary, by the purchase of carbon allowances.

## *Meeting 2008-12 commitment*

| | (Mt $CO_2$ equivalent) | |
|---|---|---|
| Emissions without any measures | 79.829 | |
| *Less* Existing measures | 8.660 | |
| Projected emissions after existing measures | | 71.169 |
| *Less* Kyoto target | | 63.032 |
| **Distance to target** | **8.137** | |
| | | |
| Additional measures | 4.953 | |
| Flexible mechanisms (i.e. carbon credits) | | 3.607 |
| **Total additional effect** | | **8.560** |

## *Sources of emissions in 2005*




## *Key sectors*

- Energy
  - 15% of electricity consumed to come from renewable sources by 2010; 33% by 2020.
  - Extended support for biomass through Bioenergy Action Plan.
- Transport
  - More sustainable transport patterns, especially through Transport 21.
  - Increased use of biofuels; 5.75% by 2010, 10% by 2020.

## *Key sectors (continued)*

- Residential
  - 40% increase in thermal performance from 2008; aiming for 60% by 2010.
  - Building Energy Ratings.
- Industry, commercial and services sector
  - Higher energy performance standards for non-residential buildings and energy management programmes.
  - Regulation of industrial gases.

## *Key sectors (continued)*

- Agriculture and land-use
  - Reduction in emissions from national herd through CAP reform.
  - Improved manure management.
  - Support for afforestation.
  - Support for energy crops; biomass harvesting scheme.

## *Key sectors (continued)*

- Public Sector
  - Energy efficiency programme with target of 33% reduction in energy use.
  - Measuring, reporting and reducing emissions.
  - Biomass heating in schools.
  - Use of biofuels in public fleets.
  - Offsetting emissions from official air travel.

## *Cross-sectoral measures*

- Use of Flexible Mechanisms.
- €15 million multi-annual awareness programme.
- Research.
- Examination of taxation incentives.
- Spatial and planning policies.
- National strategy on adaptation.

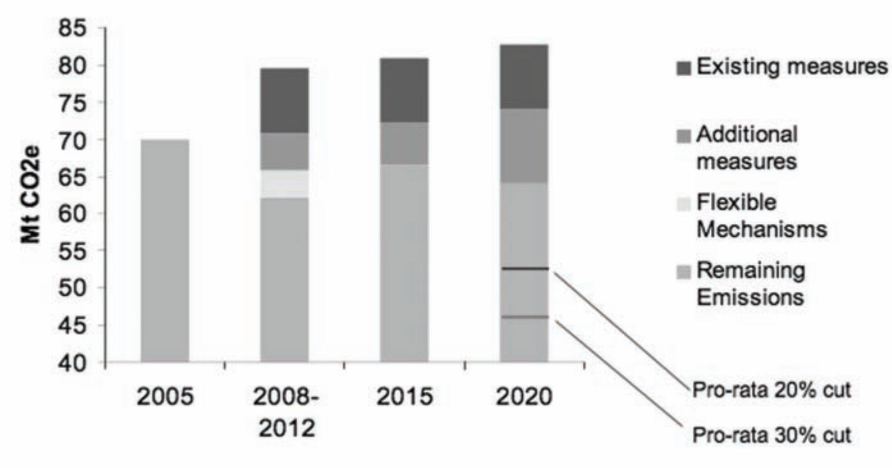
## *Post-2012 agenda*

- EU policy:
  - a unilateral commitment to achieve at least a 20% reduction of greenhouse gas emissions by 2020, compared to 1990, and
  - a 30% reduction by 2020, as its contribution to a global comprehensive agreement for the period beyond 2012, subject to participation by other developed countries and the economically more advanced developing countries.

## *Meetings of the Parties*

- 13th Conference of the Parties to the UN Framework Convention on Climate change and 3rd Meeting of the Parties to the Kyoto Protocol will take place in December 2007.
- EU expectations – to commence formal negotiations on a new agreement to be agreed at the meetings of the parties in 2009.
- Major preparatory meeting on 24th September; convened by UN Secretary General.

## *National projections to 2020*




## *Conclusion*

- Climate change is a key cross-cutting policy issue for the government.
- Policies across all relevant sectors will have to be framed in that context.
- 2020 commitments will be much more onerous than Kyoto Protocol commitment.
- Meetings of the Parties to the Climate Change Convention and Kyoto Protocol in December will be a milestone in international agenda.

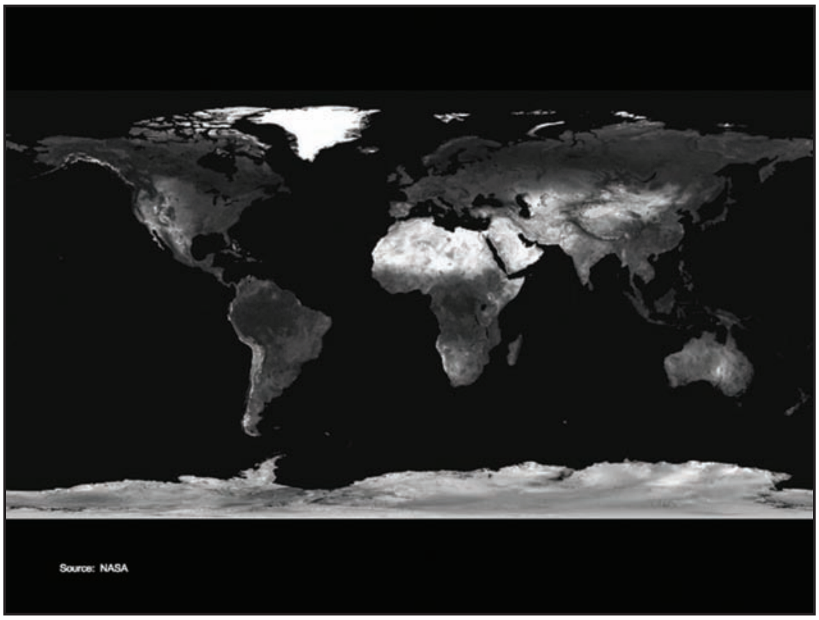
## *For copies of strategy:*

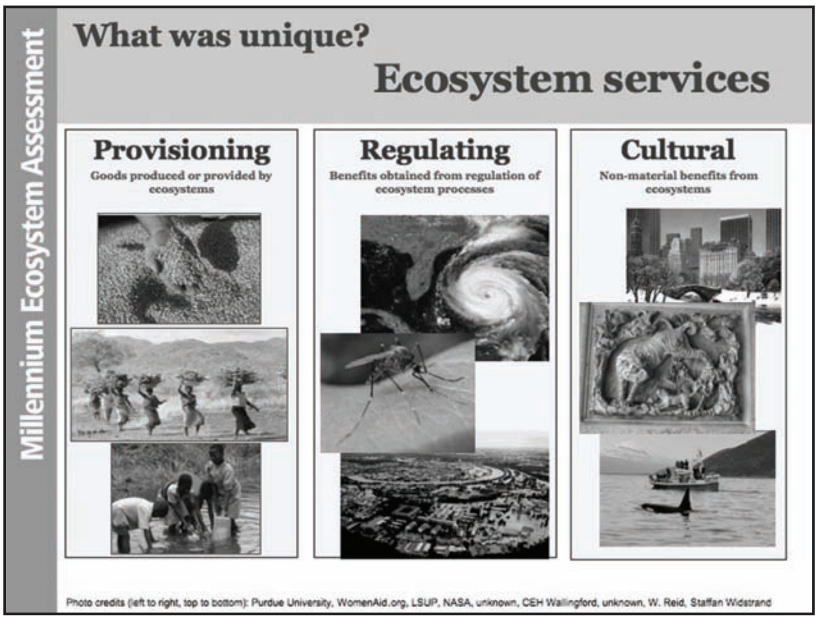
www.environ.ie

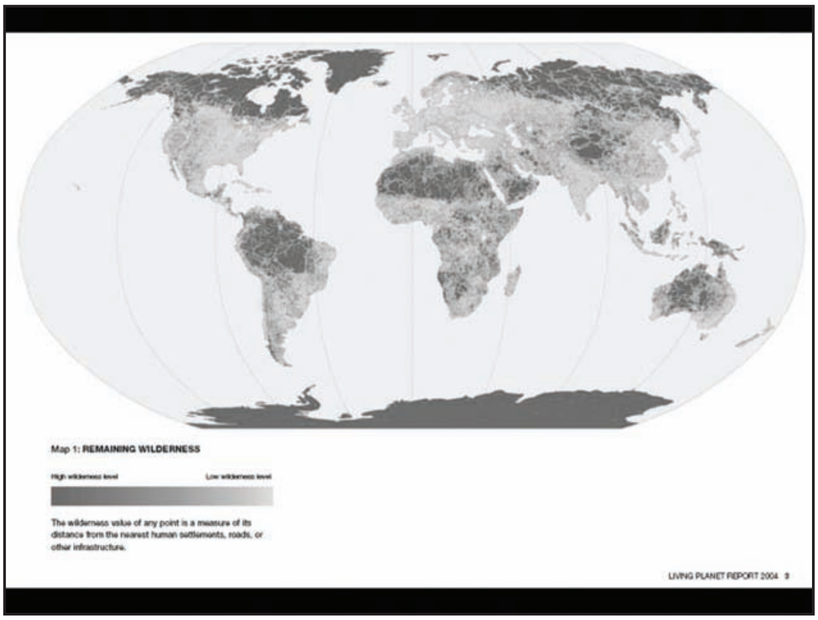
climatechangeinfo@environ.ie

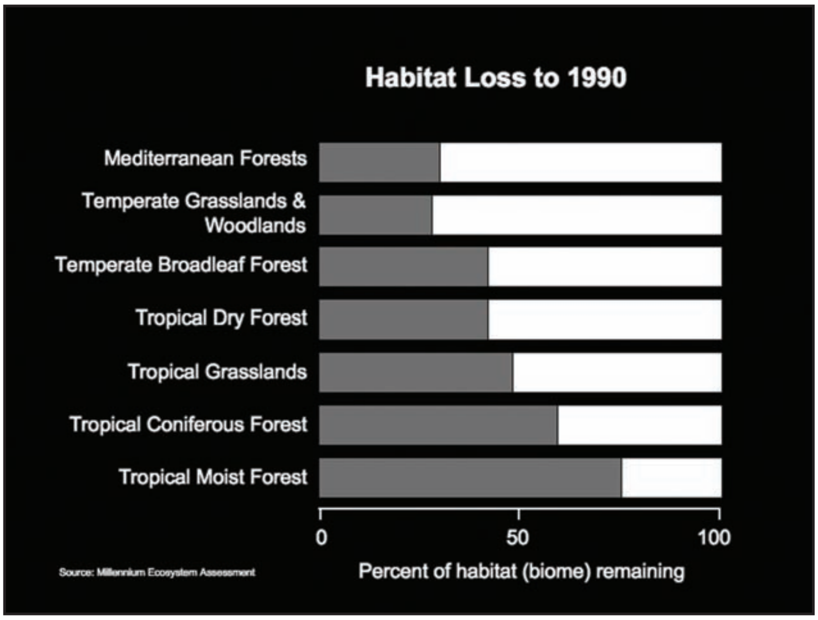
# Global forests and international climate change research

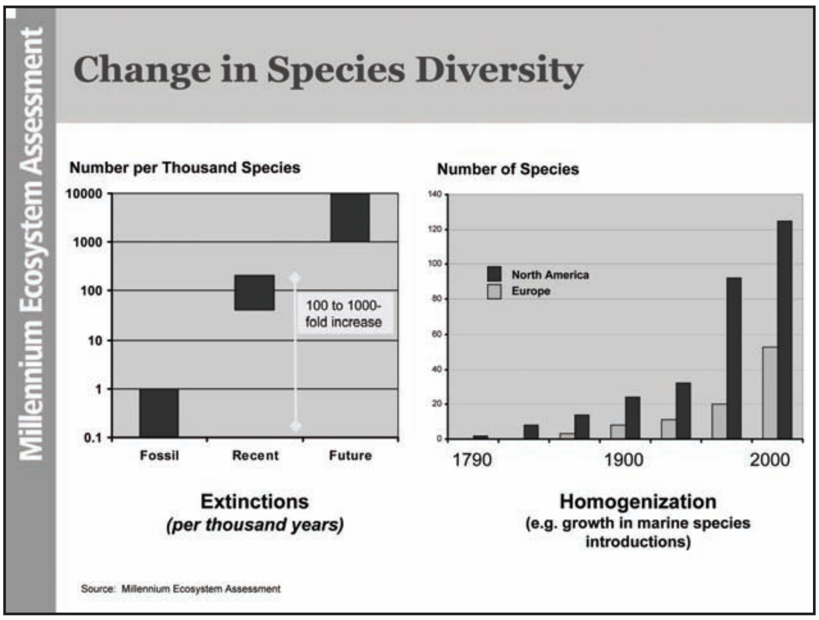
Ricardo Valentini
University of Tuscia

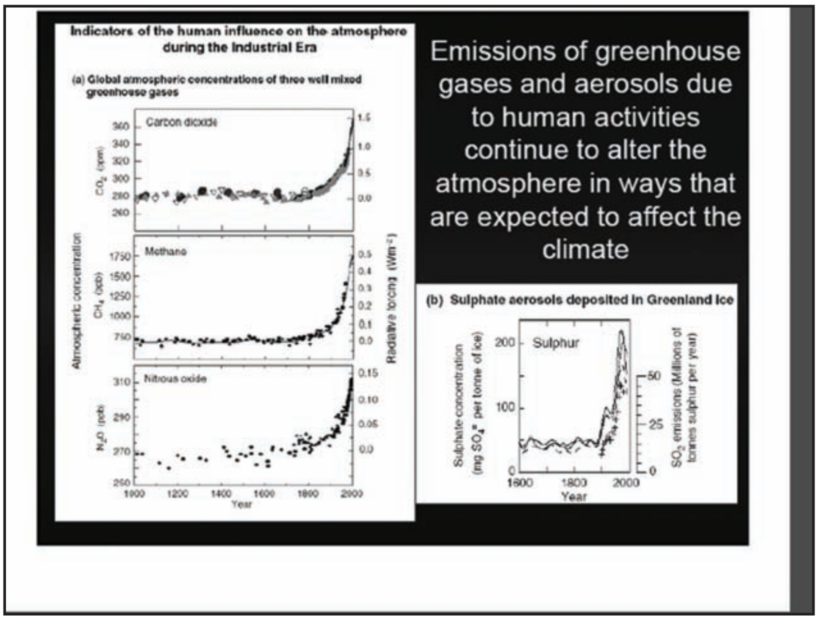


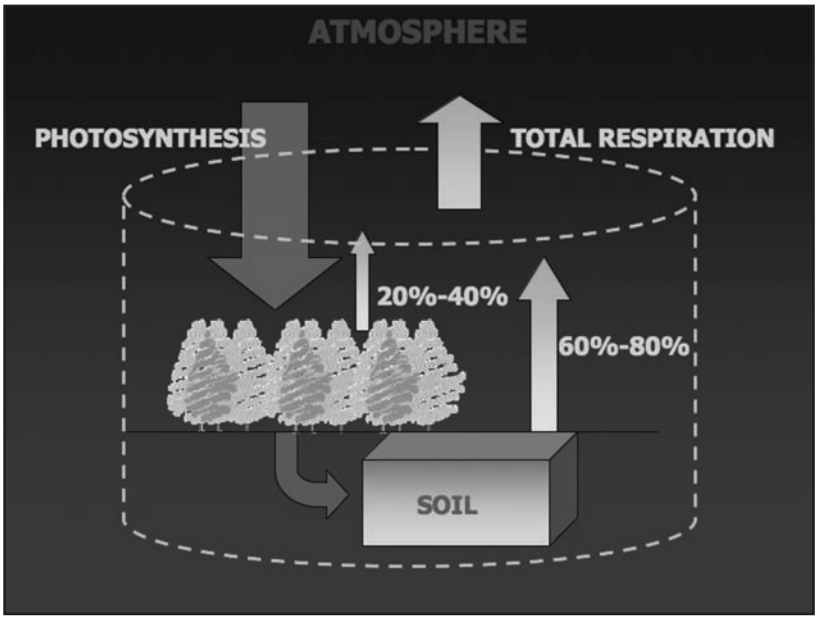



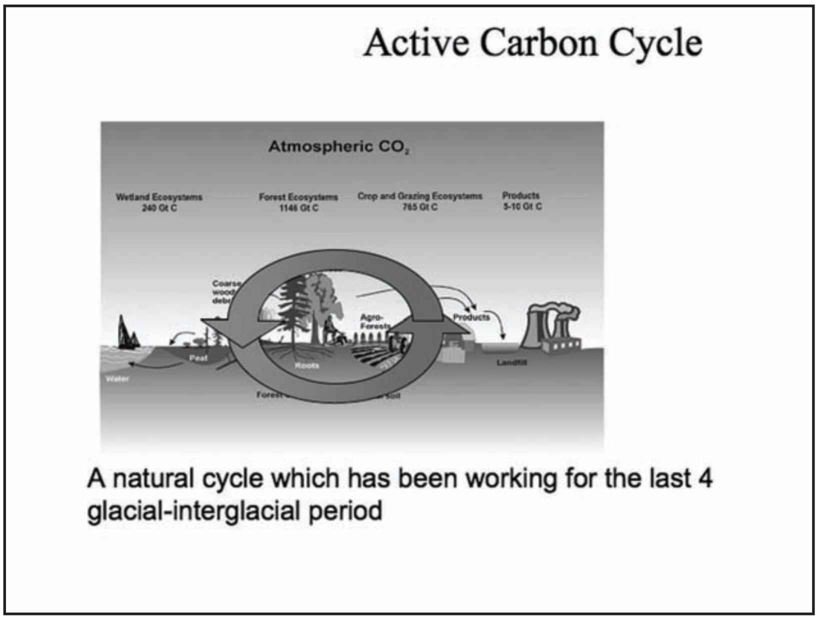

Map 1: REMAINING WILDERNESS
High wilderness level
Low wilderness level
The wilderness value of any point is a measure of its distance from the nearest human settlements, roads, or other infrastructure.
LIVING PLANET REPORT 2004 9

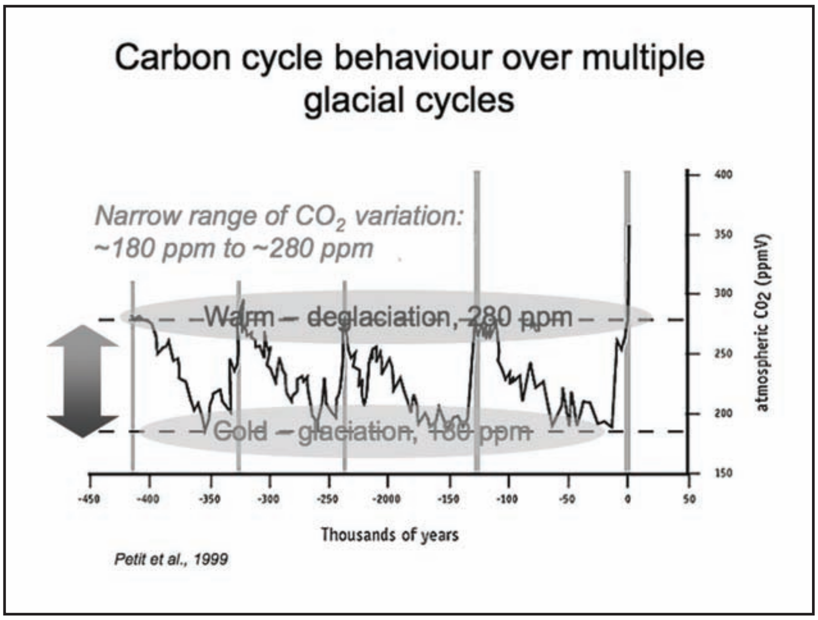

Habitat Loss to 1990
Mediterranean Forests
Temperate Grasslands & Woodlands
Temperate Broadleaf Forest
Tropical Dry Forest
Tropical Grasslands
Tropical Coniferous Forest
Tropical Moist Forest
0
50
100
Percent of habitat (biome) remaining
Source: Millennium Ecosystem Assessment

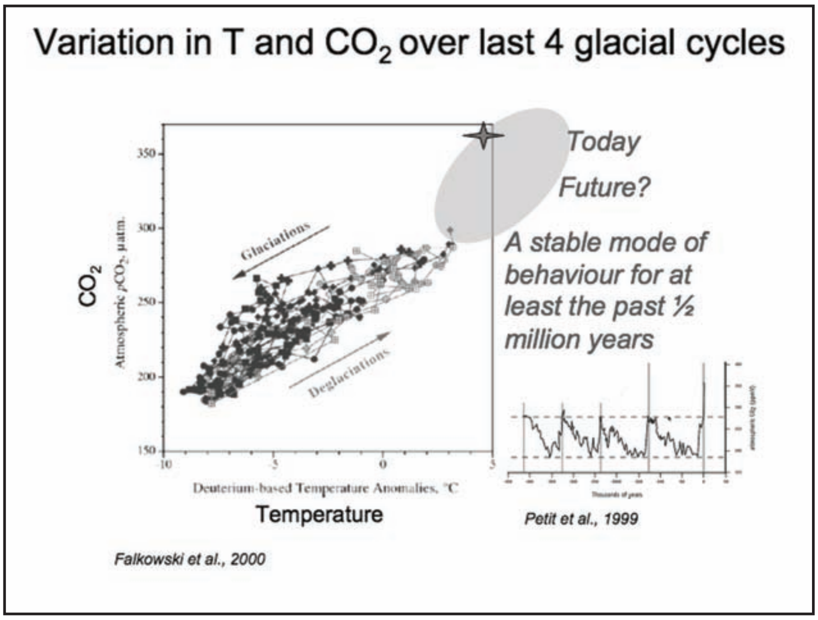

Millennium Ecosystem Assessment
Change in Species Diversity
Number per Thousand Species
10000
1000
100
10
1
0.1
100 to 1000-fold increase
Fossil
Recent
Future
Extinctions
(per thousand years)
Number of Species
140
120
100
80
60
40
20
0
North America
Europe
1790
1900
2000
Homogenization
(e.g. growth in marine species introductions)
Source: Millennium Ecosystem Assessment

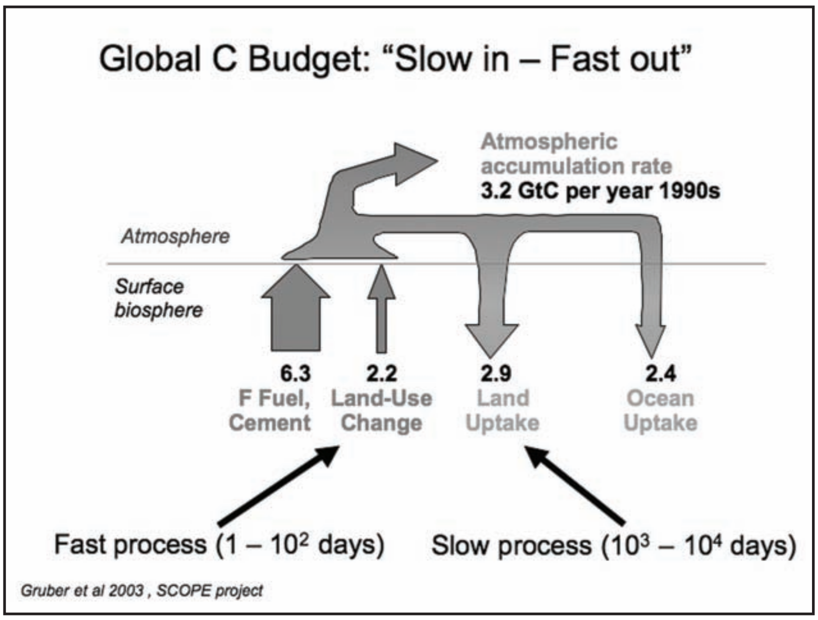

Indicators of the human influence on the atmosphere during the Industrial Era
(a) Global atmospheric concentrations of three well mixed greenhouse gases
Carbon dioxide
Methane
Nitrous oxide
Atmospheric concentration
Radiative forcing (Wm⁻²)
Year
Emissions of greenhouse gases and aerosols due to human activities continue to alter the atmosphere in ways that are expected to affect the climate
(b) Sulphate aerosols deposited in Greenland Ice
Sulphur
Year


ATMOSPHERE
PHOTOSYNTHESIS
TOTAL RESPIRATION
20%-40%
60%-80%
SOIL


Active Carbon Cycle
Atmospheric CO2
Wetland Ecosystems 240 Gt C
Forest Ecosystems 1146 Gt C
Crop and Grazing Ecosystems 765 Gt C
Products 5-10 Gt C
Peat
Water
Roots
Products
Landfill
A natural cycle which has been working for the last 4 glacial-interglacial period


Carbon cycle behaviour over multiple glacial cycles
Narrow range of CO2 variation:
~180 ppm to ~280 ppm
Warm – deglaciation, 280 ppm
Cold – glaciation, 180 ppm
atmospheric CO2 (ppmV)
Thousands of years
Petit et al., 1999


Variation in T and CO2 over last 4 glacial cycles
Today
Future?
A stable mode of behaviour for at least the past ½ million years
CO2
Atmospheric pCO2, µatm.
Glaciations
Deglaciations
Deuterium-based Temperature Anomalies, °C
Temperature
Petit et al., 1999
Falkowski et al., 2000


Global C Budget: "Slow in – Fast out"
Atmospheric accumulation rate
3.2 GtC per year 1990s
Atmosphere
Surface biosphere
6.3
F Fuel, Cement
2.2
Land-Use Change
2.9
Land Uptake
2.4
Ocean Uptake
Fast process (1 – 10² days)
Slow process (10³ – 10⁴ days)
Gruber et al 2003 , SCOPE project

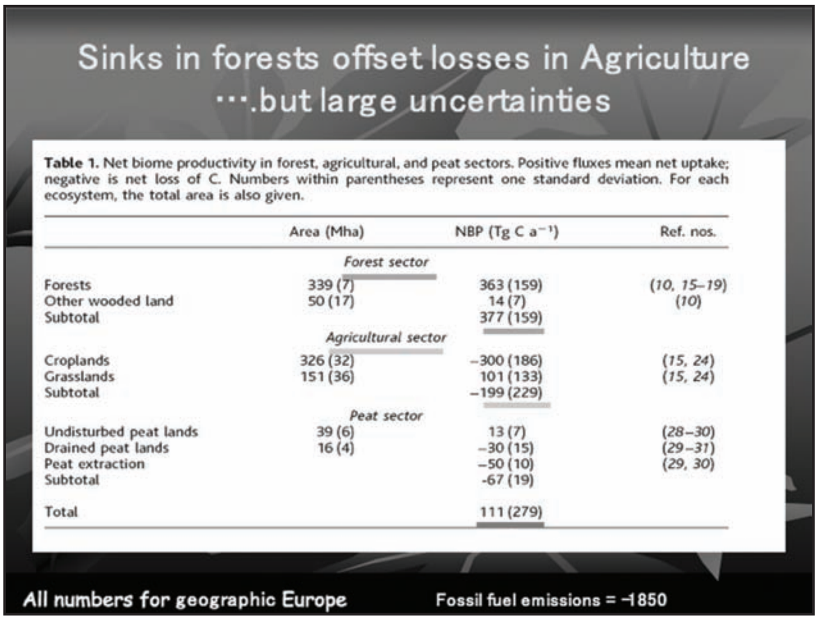
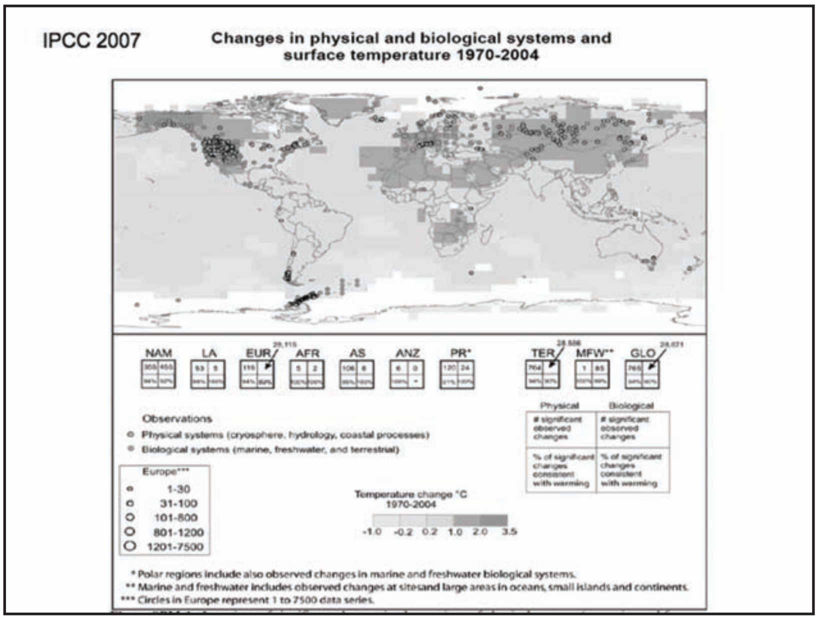
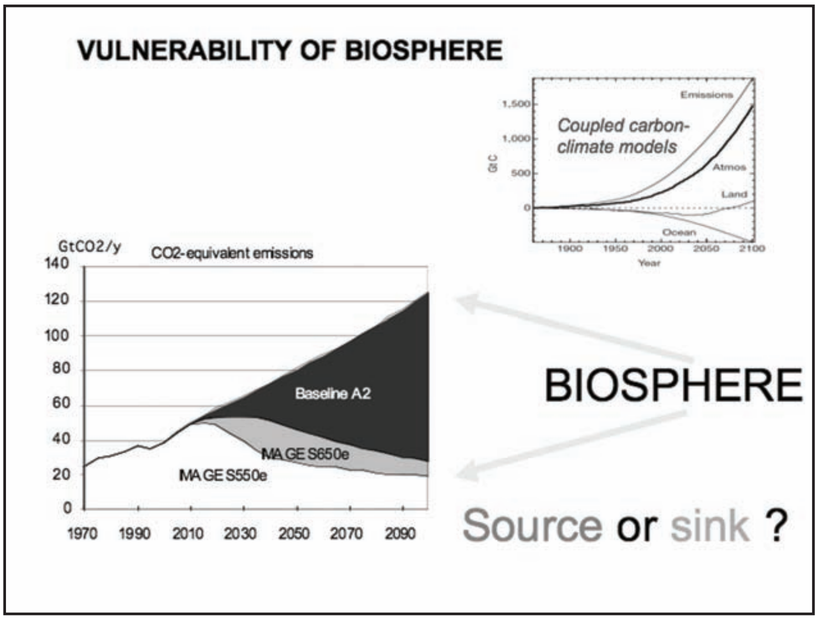
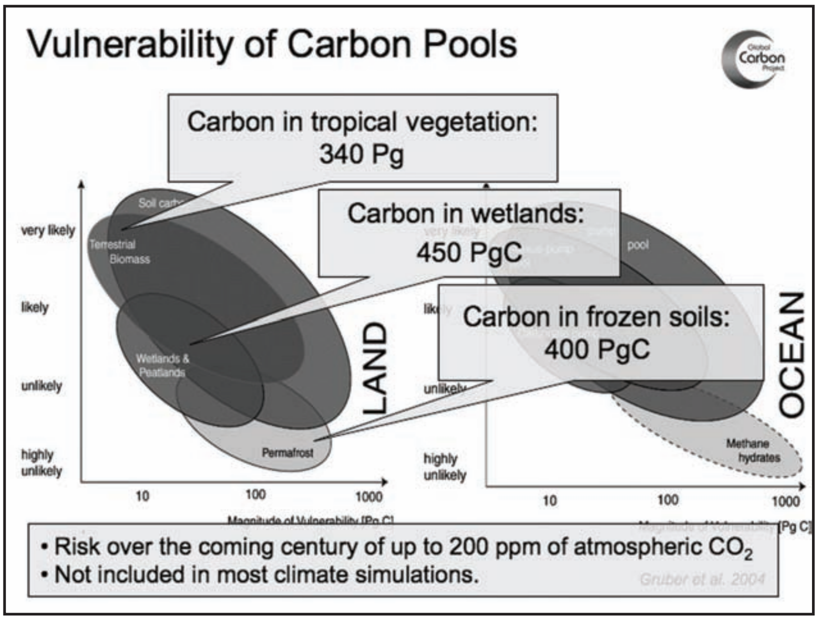


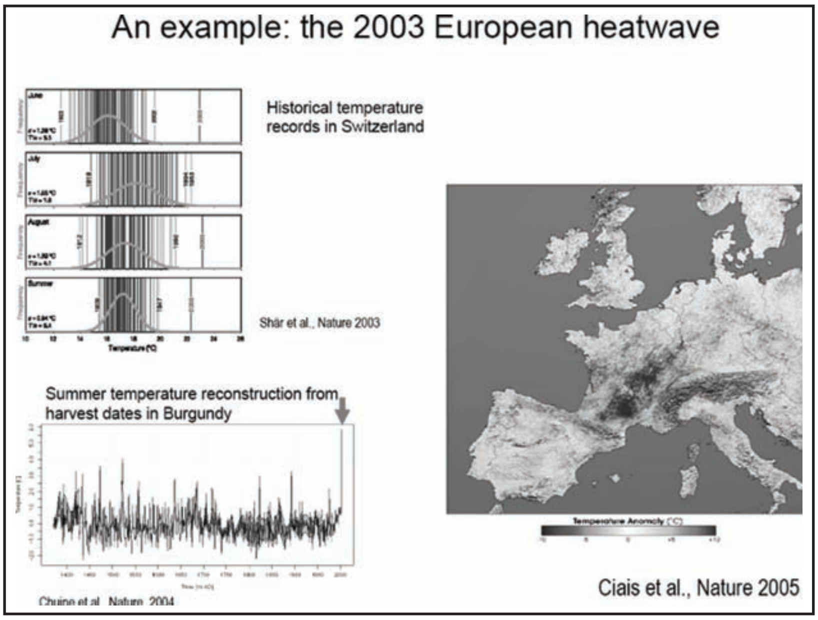

**Table 1.** Net biome productivity in forest, agricultural, and peat sectors. Positive fluxes mean net uptake; negative is net loss of C. Numbers within parentheses represent one standard deviation. For each ecosystem, the total area is also given.

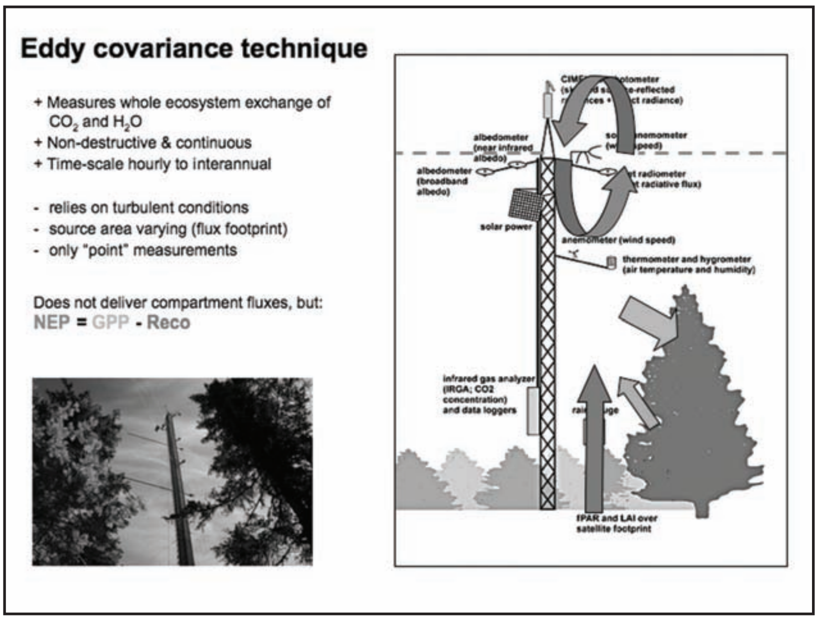
| | Area (Mha) | NBP (Tg C $a^{-1}$) | Ref. nos. |
|---|---|---|---|
| | *Forest sector* | | |
| Forests | 339 (7) | 363 (159) | *(10, 15–19)* |
| Other wooded land | 50 (17) | 14 (7) | *(10)* |
| Subtotal | | 377 (159) | |
| | *Agricultural sector* | | |
| Croplands | 326 (32) | −300 (186) | *(15, 24)* |
| Grasslands | 151 (36) | 101 (133) | *(15, 24)* |
| Subtotal | | −199 (229) | |
| | *Peat sector* | | |
| Undisturbed peat lands | 39 (6) | 13 (7) | *(28–30)* |
| Drained peat lands | 16 (4) | −30 (15) | *(29–31)* |
| Peat extraction | | −50 (10) | *(29, 30)* |
| Subtotal | | -67 (19) | |
| Total | | 111 (279) | |

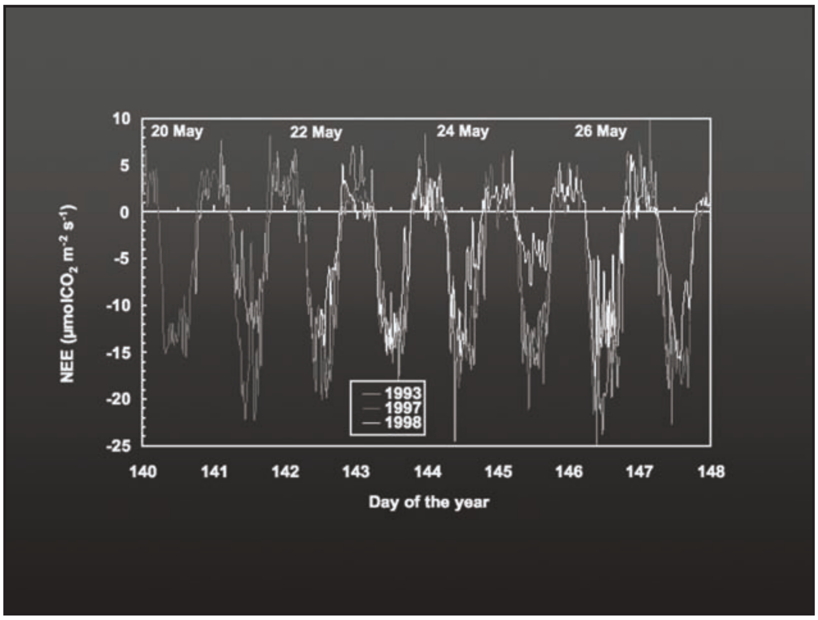


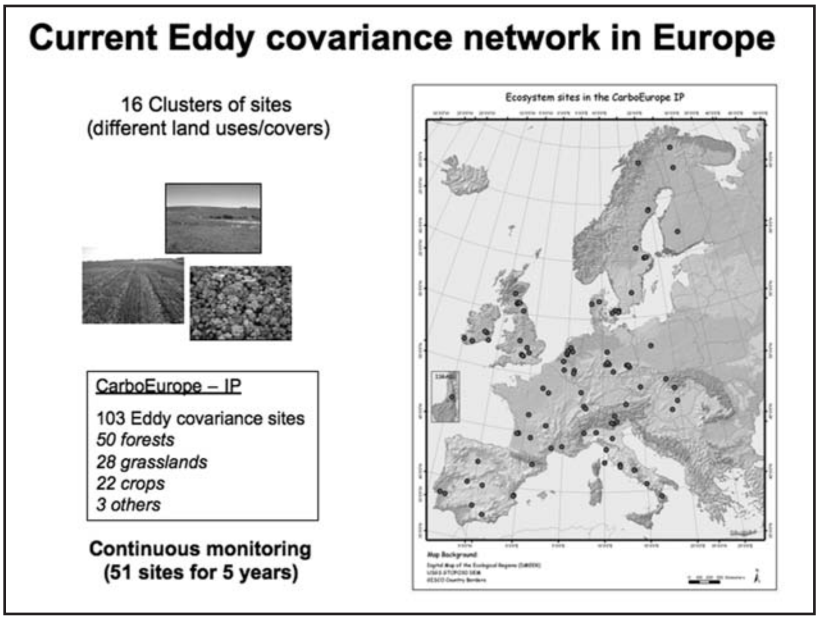

Vulnerability of Carbon Pools
Carbon in tropical vegetation: 340 Pg
Carbon in wetlands: 450 PgC
Carbon in frozen soils: 400 PgC
very likely
likely
unlikely
highly unlikely
Terrestrial Biomass
Wetlands & Peatlands
Permafrost
LAND
OCEAN
Methane hydrates
10
100
1000
• Risk over the coming century of up to 200 ppm of atmospheric $CO_2$
• Not included in most climate simulations.
Gruber et al. 2004


An example: the 2003 European heatwave
Historical temperature records in Switzerland
Shär et al., Nature 2003
Summer temperature reconstruction from harvest dates in Burgundy
Ciais et al., Nature 2005

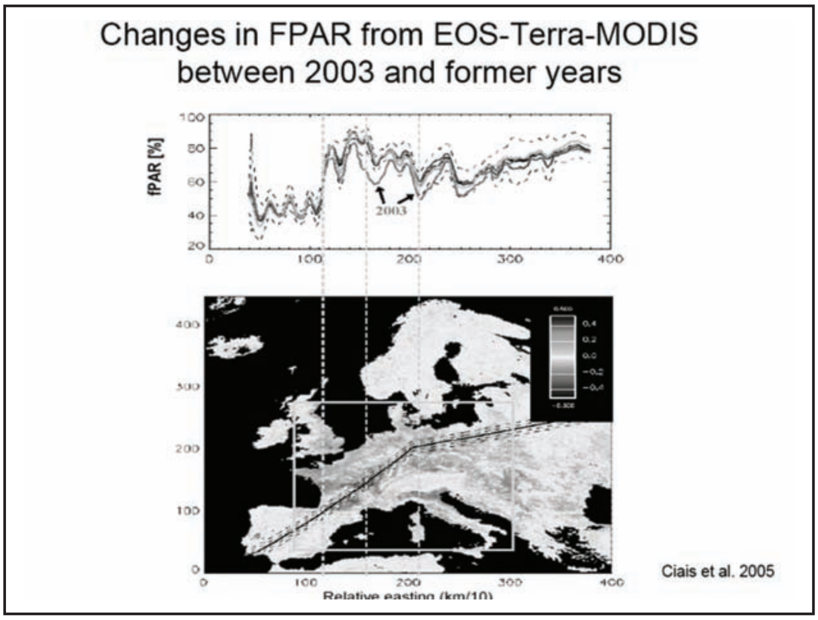

Eddy covariance technique
+ Measures whole ecosystem exchange of $CO_2$ and $H_2O$
+ Non-destructive & continuous
+ Time-scale hourly to interannual
- relies on turbulent conditions
- source area varying (flux footprint)
- only "point" measurements
Does not deliver compartment fluxes, but:
NEP = GPP - Reco
albedometer (near infrared albedo)
albedometer (broadband albedo)
solar power
anemometer (wind speed)
thermometer and hygrometer (air temperature and humidity)
infrared gas analyzer (IRGA; CO2 concentration) and data loggers
fPAR and LAI over satellite footprint



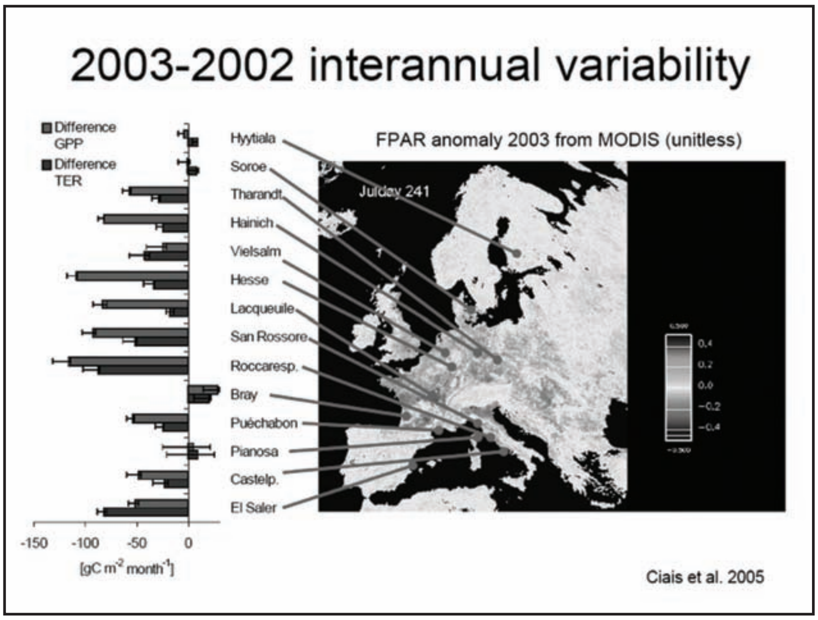
20 May
22 May
24 May
26 May
NEE (μmolCO2 m-2 s-1)
10
5
0
-5
-10
-15
-20
-25
1993
1997
1998
140
141
142
143
144
145
146
147
148
Day of the year

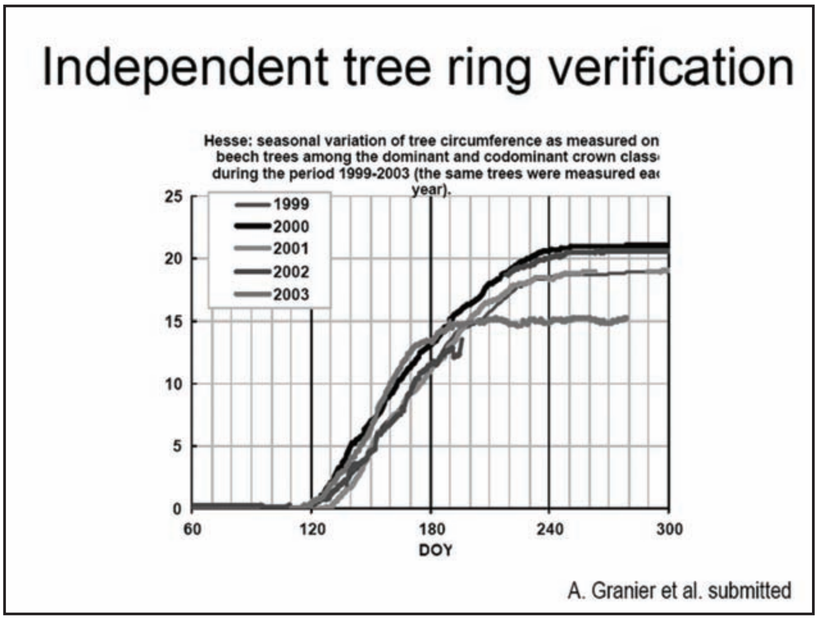



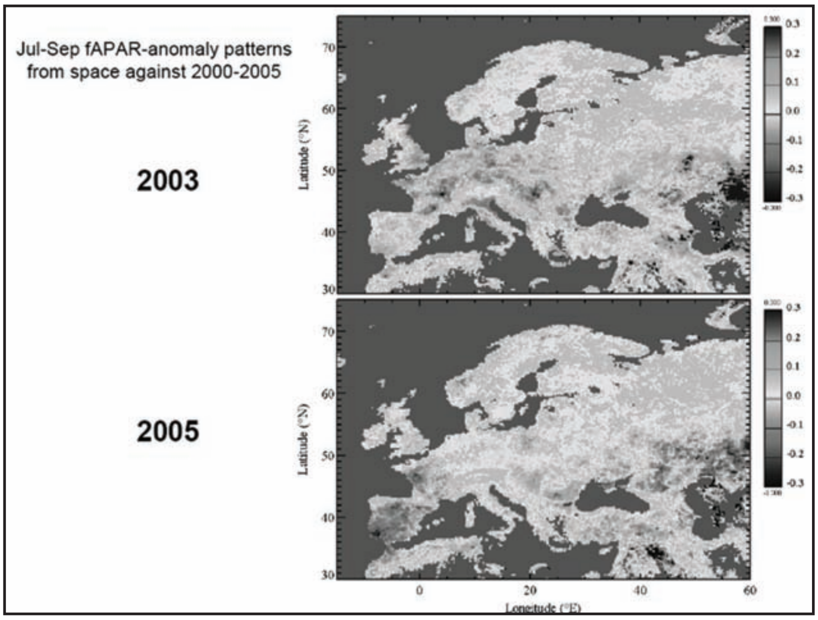
Current Eddy covariance network in Europe
16 Clusters of sites
(different land uses/covers)
CarboEurope – IP
103 Eddy covariance sites
50 forests
28 grasslands
22 crops
3 others
Continuous monitoring
(51 sites for 5 years)
Ecosystem sites in the CarboEurope IP
Map Background

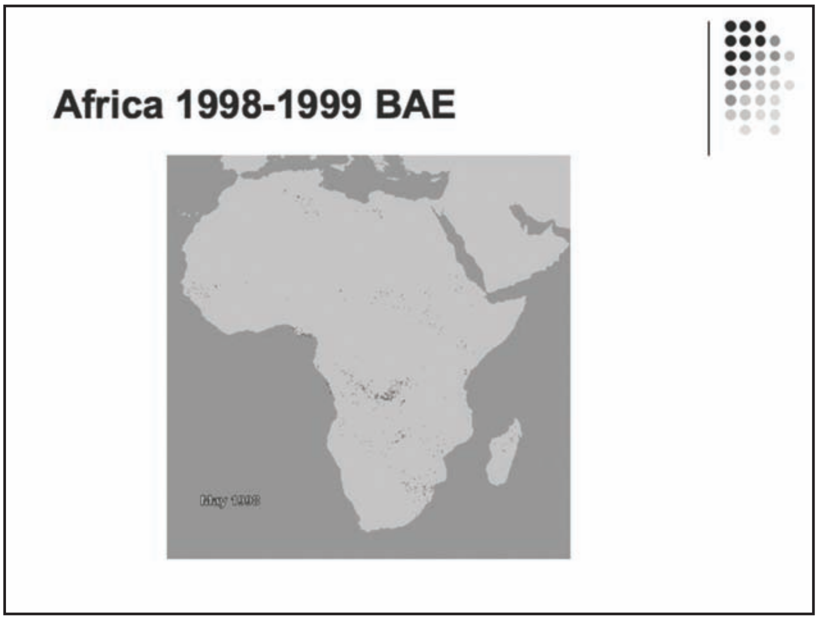
Changes in FPAR from EOS-Terra-MODIS
between 2003 and former years
fPAR [%]
2003
Relative easting (km/10)
Ciais et al. 2005

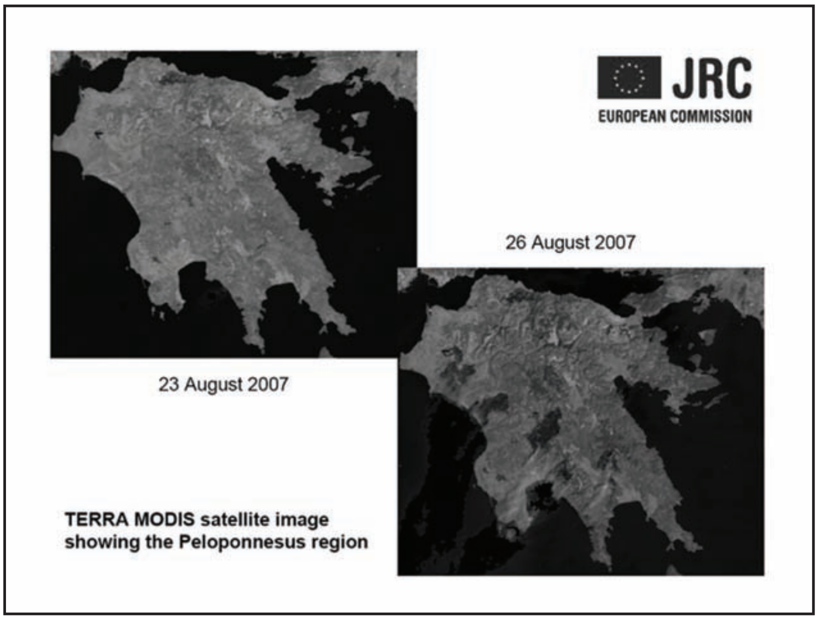

2003-2002 interannual variability
Difference GPP
Difference TER
Hyytiala
Soroe
Tharandt
Hainich
Vielsalm
Hesse
Lacqueuile
San Rossore
Roccaresp.
Bray
Puéchabon
Pianosa
Castelp.
El Saler
-150 -100 -50 0
[gC m-2 month-1]
FPAR anomaly 2003 from MODIS (unitless)
Julday 241
0.4
0.2
0.0
-0.2
-0.4
Ciais et al. 2005

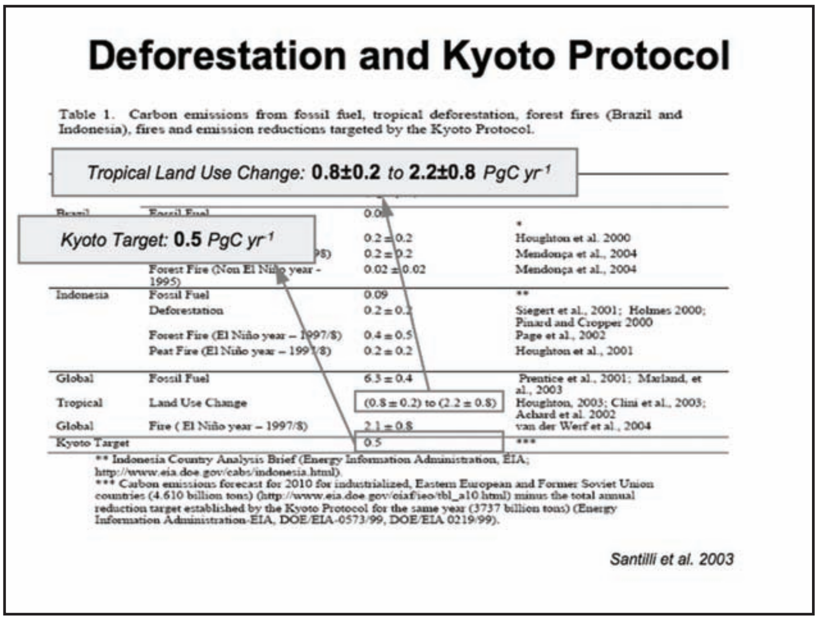

Independent tree ring verification
Hesse: seasonal variation of tree circumference as measured on beech trees among the dominant and codominant crown class during the period 1999-2003 (the same trees were measured ea year).
1999
2000
2001
2002
2003
25
20
15
10
5
0
60 120 180 240 300
DOY
A. Granier et al. submitted


Jul-Sep fAPAR-anomaly patterns from space against 2000-2005
2003
2005
Latitude (°N)
70
60
50
40
30
0.3
0.2
0.1
0.0
-0.1
-0.2
-0.3
0 20 40 60
Longitude (°E)


veja EDIÇÃO ESPECIAL
Agronegócio
Retratos de um
Brasil que dá lucros
A SAGA DA SOJA
Como a agricultura e a pecuária se tornaram motores da economia
Novos empregos, hábitos e ícones de consumo no campo
As conquistas não são definitivas. O que fazer para continuar crescendo

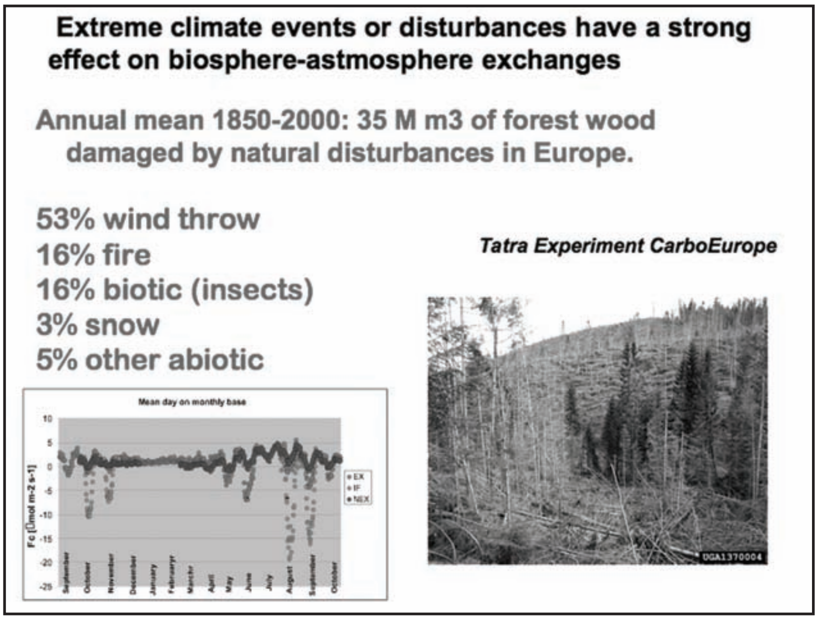

Africa 1998-1999 BAE

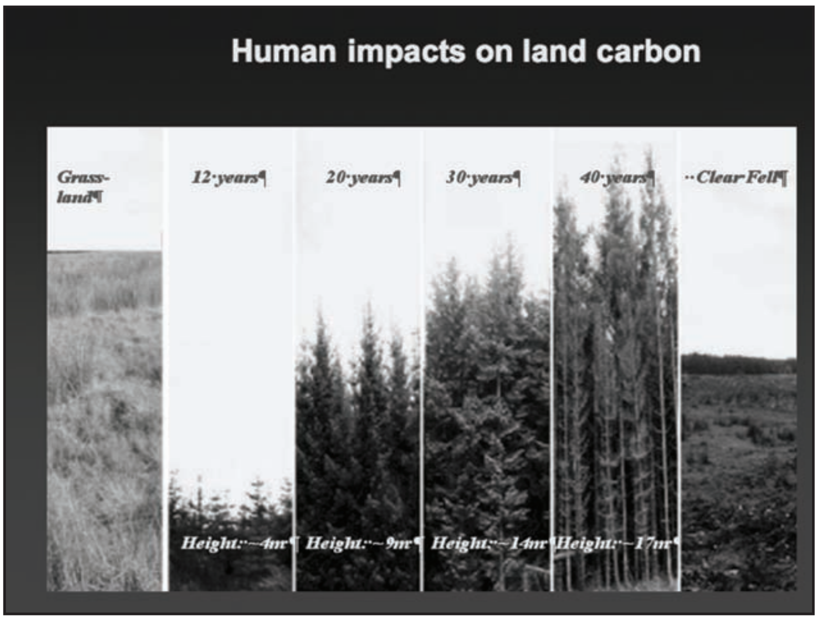

JRC
EUROPEAN COMMISSION
26 August 2007
23 August 2007
TERRA MODIS satellite image
showing the Peloponnesus region

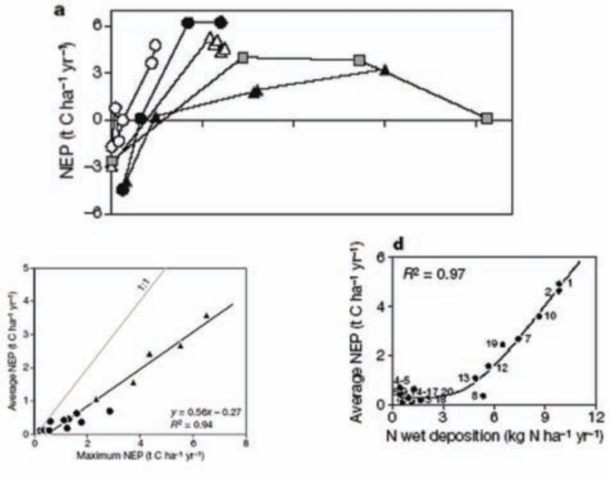

Deforestation and Kyoto Protocol
Table 1. Carbon emissions from fossil fuel, tropical deforestation, forest fires (Brazil and Indonesia), fires and emission reductions targeted by the Kyoto Protocol.
Tropical Land Use Change: 0.8±0.2 to 2.2±0.8 PgC yr-1
Kyoto Target: 0.5 PgC yr-1

| | | | |
|---|---|---|---|
| | | 0.0 | * |
| | | 0.2 ± 0.2 | Houghton et al. 2000 |
| | | 0.2 ± 0.2 | Mendonça et al., 2004 |
| | Forest Fire (Non El Niño year - 1995) | 0.02 ± 0.02 | Mendonça et al., 2004 |
| Indonesia | Fossil Fuel | 0.09 | ** |
| | Deforestation | 0.2 ± 0.2 | Siegert et al., 2001; Holmes 2000; Pinard and Cropper 2000 |
| | Forest Fire (El Niño year – 1997/8) | 0.4 ± 0.5 | Page et al., 2002 |
| | Peat Fire (El Niño year – 1997/8) | 0.2 ± 0.2 | Houghton et al., 2001 |
| Global | Fossil Fuel | 6.3 ± 0.4 | Prentice et al., 2001; Marland, et al., 2003 |
| Tropical | Land Use Change | (0.8 ± 0.2) to (2.2 ± 0.8) | Houghton, 2003; Clini et al., 2003; Achard et al. 2002 |
| Global | Fire ( El Niño year – 1997/8) | 2.1 ± 0.8 | van der Werf et al., 2004 |
| Kyoto Target | | 0.5 | *** |

** Indonesia Country Analysis Brief (Energy Information Administration, EIA; http://www.eia.doe.gov/cabs/indonesia.html).
*** Carbon emissions forecast for 2010 for industrialized, Eastern European and Former Soviet Union countries (4.610 billion tons) (http://www.eia.doe.gov/oiaf/ieo/tbl_a10.html) minus the total annual reduction target established by the Kyoto Protocol for the same year (3737 billion tons) (Energy Information Administration-EIA, DOE/EIA-0573/99, DOE/EIA 0219/99).
Santilli et al. 2003

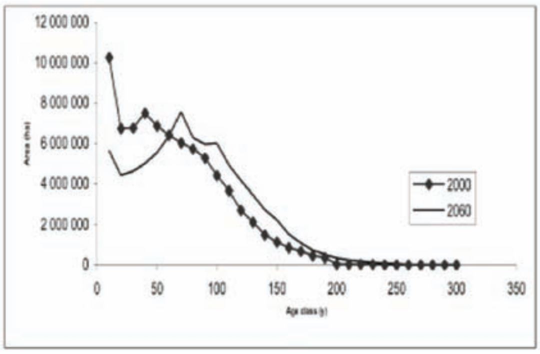

Extreme climate events or disturbances have a strong effect on biosphere-astmosphere exchanges
Annual mean 1850-2000: 35 M m3 of forest wood damaged by natural disturbances in Europe.
53% wind throw
16% fire
16% biotic (insects)
3% snow
5% other abiotic
Tatra Experiment CarboEurope
Mean day on monthly base
Fc [μmol m-2 s-1]
EX
IF
NEX
September
October
November
December
January
February
March
April
May
June
July
August
September
October


Human impacts on land carbon
Grass-land
12 years
20 years
30 years
40 years
Clear Fell
Height: ~4m
Height: ~9m
Height: ~14m
Height: ~17m




(Magnani et al. 2007, Nature)

European forests – the future challenge in management




# CONCLUSIONS

- **The terrestrial carbon sink is acting to remove about 30% of total GHG emission.**
- **However, vulnerability of carbon uptake is impaired by :**

1. **Climate change feed-backs**
2. **Human activities**

- **A national adaptation plan to Climate Changes should consider as a priority sustainable forest management through, i.e. forets conservation, restoration of degraded areas, soil conservation, biodiversity enhancement, fire protection etc.**