- *Increasing atmospheric levels of greenhouse gases (GHGs), derived from the burning of fossil fuel, deforestation, land-use change and industrial processes, are causing climate change.*
- *Forests play an important role in the global carbon cycle; a clear understanding of this role is necessary to comprehend and combat the climate change and its consequences.*
- *There are a number of ways that forests can be used to influence GHG emissions to the atmosphere, not only through the maintenance of existing forests and the creation of new ones, but also in the utilisation of wood products for energy and in the displacement of energy intensive products.*
- *The rate of C sequestration can be affected by many factors, including changes in land use, forest management activities such as harvesting and fertilisation, changes in climate, nitrogen deposition and disease outbreaks.*
- *The Kyoto Protocol has established targets for the reduction of GHG emissions and identified mechanisms by which these can be achieved. The rules and modalities for achieving these reductions are set out in the Marrakesh Accords.*
- *Forest inventories provide a practical basis for estimating stocks of carbon in biomass.*

COFORD
Agriculture Building
Belfield, Dublin 4, Ireland
Telephone: +353 1 716 7700
Email: info@coford.ie
http://www.coford.ie

Carbon Sequestration in Irish Forests

Kenneth A. Byrne[1] and Kevin Black[2]

Introduction

There is general consensus among the scientific community that increasing atmospheric levels of the so-called ‘greenhouse gases’ are causing climate change and are likely to continue doing so. The principal greenhouse gases (GHGs) are:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)

These gases arise mainly from the burning of fossil fuel, deforestation, other land-use change, and industrial processes.

The forest carbon cycle

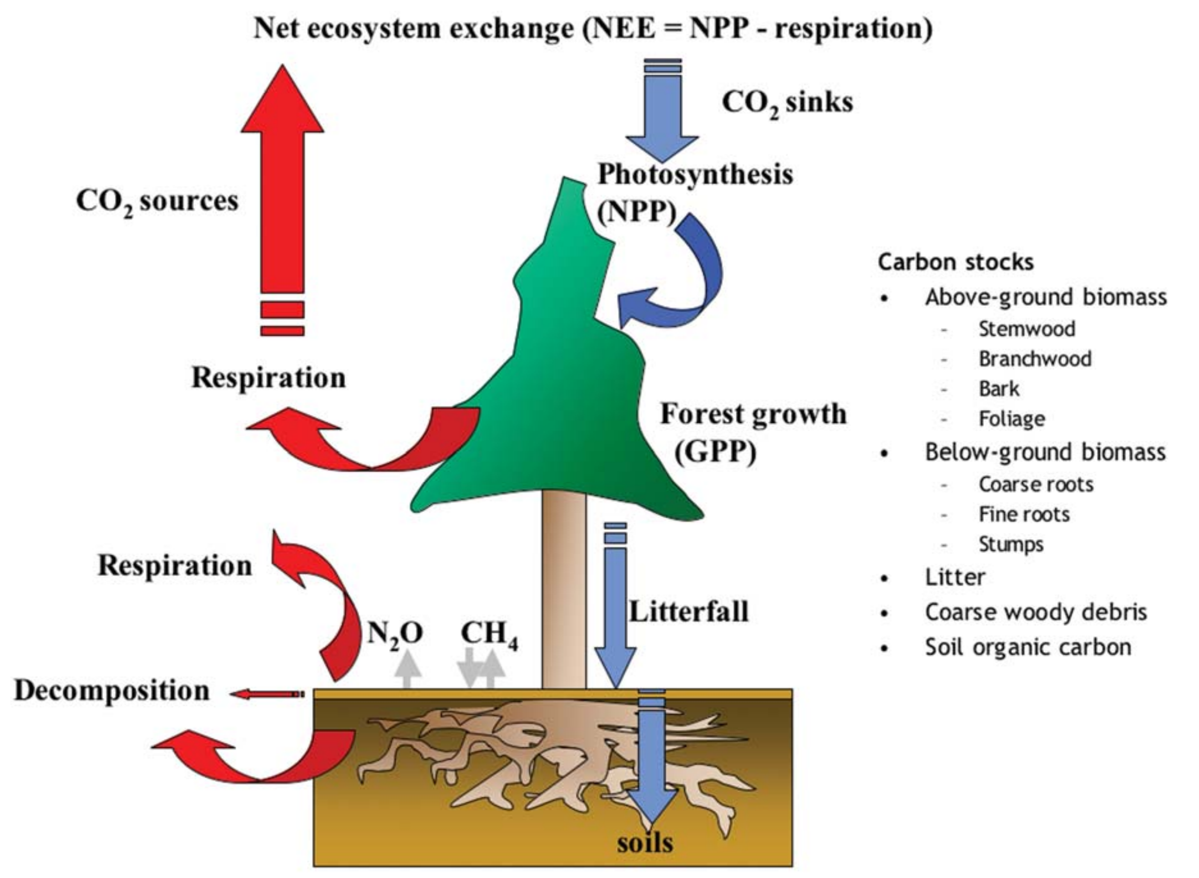
The ability of forests to store and sequester atmospheric carbon is well known and established. Indeed, forests represent the largest global terrestrial store of carbon, containing approximately 39% of global soil carbon and 77% of global vegetation carbon (Bolin *et al*. 2000). Terrestrial ecosystems are both sources and sinks for carbon. For instance, during the 1990s terrestrial ecosystems sequestered 22% of the carbon released by fossil fuel emissions. On the other hand, land-use change in the same period (e.g. afforestation, deforestation, agriculture and fire) was a net source of C release to the atmosphere equivalent to approximately 34% of fossil fuel emissions (Houghton 2002). It is therefore evident that forests and land-use play an important role in the global carbon cycle and that a clear understanding of this role is a vital component of attempts to understand and combat the causes and consequences of climate change.

[1] *Forest Ecosystem Research Group, Department of Environmental Resource Management, Faculty of Agriculture, University College Dublin, Belfield, Dublin 4. Email: kenneth.byrne@ucd.ie*
[2] *Department of Botany, Faculty of Science, University College Dublin, Belfield, Dublin 4. Email: kevin.black@ucd.ie*

The C cycle in forests is characterised by a number of 'pools' and 'fluxes'. Pools are locations of carbon in the forest, such as above- and below-ground biomass, forest floor and soil. Each pool contains a quantity of C that is referred to as the 'stock'. Carbon transfers between pools by many different processes, including photosynthesis, respiration and combustion. These processes are known as 'fluxes'. The net exchange of C between a forest and the atmosphere is determined by two large fluxes. The first of these is C uptake as a result of photosynthesis. The second is the loss of C as a result of respiration by trees, both above and below ground, and decomposition of soil organic matter. If C uptake exceeds loss, the forest is a 'sink'. Conversely, if loss exceeds uptake the forest is a 'source'. The rate of sequestration can be affected by many factors, such as species, yield class, soil type, management activities such as harvesting and fertilisation and previous land use.

Average rate of C sequestration in forest plantations during a single rotation (after Dewar and Cannell 1992).

	Yield Class	C Sequestration Rate (t C/ha/yr)
Sitka spruce	24	4.4
	22	4.3
	20	4.1
	18	3.8
	16	3.6
Beech	6	2.4
Oak	4	1.8



Carbon stocks and fluxes in forest ecosystems.

The C cycle also extends beyond the forest through the use of forest products. These products form another pool and include solid timber, paper and board products.

How can forests help?

There are a number of means by which forests can be used to influence greenhouse gas emissions to the atmosphere. These are:

Plant new forests

New forests have the potential to take CO_2 from the atmosphere and store it in vegetation and soils. However, the sink potential of forests may be greatly reduced if they are planted on carbon-rich soils, especially peatlands. On peats, drainage and tree planting may accelerate organic matter decomposition, thereby increasing soil CO_2 emissions and reducing the net sink.

Manage existing forests for increased C storage

C stocks in existing forests can be increased by management activities such as forest fertilization, pest management, continuous forest cover, limited soil disturbance (cultivation) before planting, harvest quantity and timing, and reduced impact harvesting.

Substitute wood for non-wood fossil fuels and building materials

Wood when burned for heat or electricity production is a 'carbon neutral' energy source. If it is used to displace fossil fuel energy sources it can help to reduce GHG emissions. See the COFORD Connects *Wood as a Renewable Source of Energy* (Healion 2002) for further information.

Substitution of energy-intensive products derived from aluminium, concrete and steel by wood products significantly reduces the energy cost of buildings.

Kyoto Protocol

The first global attempt to deal with climate change was the United Nations Framework Convention on Climate Change (UNFCCC), which was agreed at the Earth Summit in Rio in 1992. Ireland ratified the UNFCCC in 1994. As a Party it provides annual inventories of GHG emissions by sources and removals by sinks. This was followed by the Kyoto Protocol, which was agreed in December 1997. Its salient features are:

- Developed countries (so-called Annex I) committed to reduce annual GHG emissions to 5.2% below 1990 levels by the first commitment period of 2008-2012.
- The European Union as whole committed to a reduction of 8%.
- The Protocol could only enter into force when ratified by 55% of Annex I countries, which cumulatively represent 55% of global GHG 1990 emission levels.
- The Protocol made provision for the use of carbon sequestration by forests as a means to achieve compliance with overall GHG emission reduction targets.

In recognition of the differences in the degree of economic development between Member States, the EU Union negotiated an agreement to share its reduction commitment. Ireland is committed to limiting its GHG emissions to 13% above 1900 levels by the first commitment period. This presents a major challenge, as current estimates indicate that emissions in 2002 were 31% above 1990 levels.

Although the Protocol established targets for the reduction of GHG emissions and identified mechanisms by which this could be achieved it did not spell out the rules, modalities, etc. for achieving such reductions. These were agreed at COP7 in Marrakesh in November 2001 with the completion of the 'Marrakesh Accords'.

There are two principal articles in the Kyoto Protocol under which countries may use forest sinks to offset GHG emissions. 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 that have taken place since 1990. Article 3.4 refers to additional human-induced activities in the agriculture, land-use change and forestry sectors, again which have taken place since 1990, but in the case of forests applies only to those which were in existence prior to 1990, in order to avoid double accounting.

Under the terms of the Marrakesh Accords there is no limit to the amount of credit a Party (e.g. Ireland) may claim under Article 3.3. Forest management is one of the eligible activities under Article 3.4 and the amount of credit Ireland may claim has been set at 50,000 tonnes of carbon/year during the first commitment period. Clearly accounting for all carbon stocks in Irish forests and how they change with time in a manner, which meets the needs of the Kyoto Protocol, is a considerable task. While guidance on this will be provided by the forthcoming Intergovernmental Panel on Climate Change report on *Good Practice Guidance for Land Use, Land Use Change and Forestry* there is a need for nationally specific data to reflect the attributes of Irish forests.

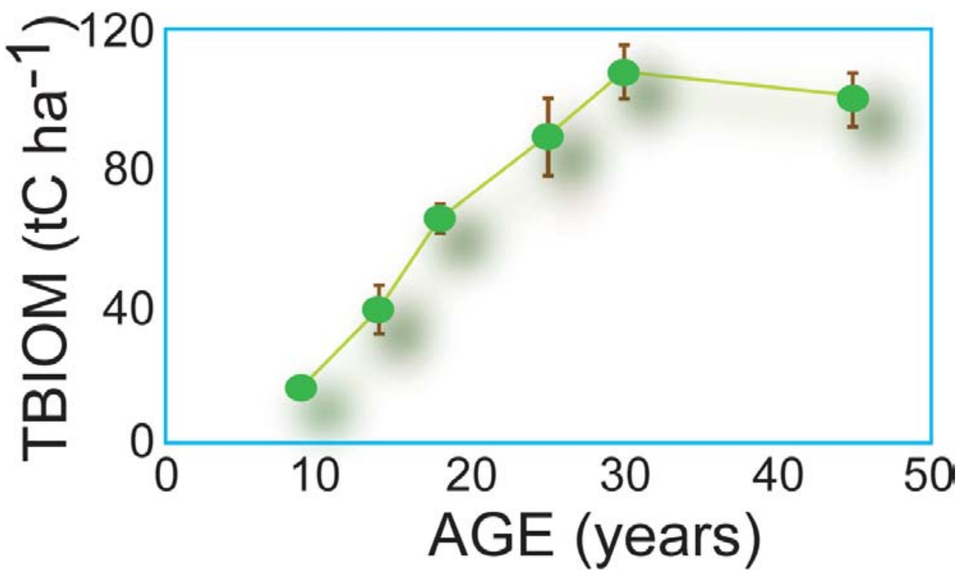
Measuring C sequestration in forests

Forest inventories can provide a practical means of estimating stocks of biomass C. Since forest inventories are usually targeted towards the characterization of timber stocks and growth there are uncertainties involved in converting these measures into total forest carbon stock and stock changes. Biomass carbon stocks are usually calculated using biomass expansion factors (BEFs). The BEF is the ratio of total biomass to merchantable volume and can be applied to forest inventory to calculate total biomass C stocks. If data exist on the rate of stemwood increment the rate of C sequestration can be calculated on an annual or periodic annual basis. BEFs vary with factors such as soil type, species, yield class, stocking density, age and diameter distribution and it is best to use BEF estimates which account for this variation.

Although soil carbon stocks can increase following afforestation, they are difficult to detect with a high degree of accuracy, because the input of new carbon into soils is small compared to the large background pool of soil carbon. In addition, there is a large degree of spatial variability within a stand and between stands of the same age or planting density. These two factors make changes in soil carbon stocks very difficult to detect. Models may be developed in the near future which would allow these changes to be estimated.

C sequestration in Irish forests

Our ability to estimate the amount of carbon sequestered in Irish forests is at an early stage of development. However, given that the forest estate is relatively young, with a large increase in new forests over the last decade there is considerable potential for the use of forest C sequestration



Age related changes in total biomass C stocks in Sitka spruce forests (TBIOM) (Black et al. in press).

to help meet our Kyoto Protocol commitments. Kilbride *et al*. (1999) estimated that Irish forests on average sequester 3.36 t C ha^{-1} yr^{-1}. However this value is likely to change in the future as more information becomes available as a result of ongoing research.

COFORD has developed a model – CARBWARE – that estimates the rate of uptake of carbon in the national forest as a whole. It is the basis for reporting carbon stocks and stock changes to the UNFCCC.

Conclusions

Forests play an important role in the global carbon cycle and the maintenance of forests is a vital component of any efforts to mitigate climate change. At national level, forests have the potential to play a significant role not only through the maintenance of existing forests and the creation of new ones, but also in the utilisation of wood products for energy and in the displacement of energy intensive products. Although recent years have seen considerable advances in our understanding of the C balance in Irish forests many

THE SCIENTIFIC APPROACH

In comparison with forest inventory methods, micrometeorological ('flux tower') methods, such as eddy covariance, provide a way of directly measuring stand level C fluxes (see Plate 1). In this technique, the vertical velocity and gas concentrations of atmospheric eddies (pockets of air) are sampled every 20 Hz. Averaging the product of the recorded fluctuations in gas concentrations and vertical wind speeds over a period of about 30 minutes yields the net amount of material being transported between the biosphere and the atmosphere. Continuous measurements can allow the net exchange of CO_2, heat and water between the forest and the atmosphere to be measured at a high temporal resolution, representing a large forest area (up to 60 ha). This methodology is highly developed (Aubinet et al. 2000) and has been widely applied in forest ecosystems (e.g. Lindroth et al. 1998, Schulze et al. 1999). These can be used to improve total C stock estimates, which are often under-estimated using conventional inventory approaches. Additional measurements of soil, stem and foliar biomass C fluxes are essential to partition the fluxes between soil and biomass. They also facilitate process level investigation of soil C cycling, which is critical to understanding the mechanisms controlling C flow between the forest and the atmosphere.

The eddy covariance system (A, B), soil (C) and bole (D) respiration chambers used for the collection of continuous flux and respiration data.

information gaps remain before a robust C accounting system can be created for Irish forests. Principal among these is a plot-based forest inventory repeated every five to ten years. Current research efforts will provide valuable information and understanding which, combined with forest inventory data, will lay the foundations of a C accounting system which will meet the standards of best international practice.

References

Aubinet, M., Grelle, A., Ibrom, A., Rannik, Ü., Moncrieff, J., Foken, T., Kowalski, A.S., Martin, P.H., Berbigier, P., Bernhofer, C.H., Clement, R., Elbers, J., Granier, A., Grünwald, T., Morgenstern, K., Pilegaard, K., Rebmann, C., Snijders, W., Valentini, R. and Vesala, T. 2000. Estimates of the annual net carbon and water exchange of forests: the euroflux methodology. *Advances in Ecological Research* 30, 113-175.

Black, K., Tobin, B., Saiz, G., Byrne, K. and Osborne, B. 2003. Improved estimates of biomass expansion factors for Sitka spruce. *Irish Forestry*. In press.

Bolin, B., Sukumar, R., Ciais, P., Cramer, W., Jarvis, P., Kheshgi, H., Nobre, C., Semonov, S. and Steffen, W. 2000. *1. Global Perspective*. In: Watson, R.T., Noble, I.R., Bolin, B., Ravindranath, N.H., Verardo, D.J. and Dokken, D.J. (eds.) 2000. Land Use, Land-Use Change, and Forestry. Cambridge University Press, pp. 23-52.

Dewar, R.C. and Cannell, M.G.R. 1992. Carbon sequestration in the trees, products and soils of forest plantations: an analysis using UK examples. *Tree Physiology* 8:239–258.

Healion, K. 2002. *Wood as a Renewable Source of Energy*. COFORD Connects, Socio-Economic Aspects of Forestry, 1, 8pp.

Houghton, R.A. 2002. Magnitude, distribution and causes of terrestrial carbon sinks and some implications for policy. *Climate Policy* 2: 71-88.

Lindroth, A., Grelle, A. and Morén, A-S. 1998. Long-term measurements of boreal forest carbon balance reveal large temperature sensitivity. *Global Change Biology* 4: 443-450.

Schulze, E-D., Lloyd, J., Kelliher, F.M., Wirth, F.M., Rebmann, C., Lühker, B., Mund, M., Knohl, A., Milyukova, I.M., Schulze, W., Ziegler, W., Varlagin, A.B., Sogachev, A.F., Valentini, R., Dore, S., Grigoriev, S., Kolle, O., Panfyorov, M.I., Tchebakova, N. and Vygodskaya, N.N. 1999. Productivity of forests in the Eurosiberian boreal region and their potential to act as a carbon sink – a synthesis. *Global Change Biology* 5: 703-722.