- *Peatlands store a large pool of carbon, part of which is prone to oxidation and loss as carbon dioxide (CO_2) following afforestation.*
- *Recent information suggests that CO_2 emissions following afforestation are smaller than previously thought. This is due to:*
  - *uptake and storage of CO_2 by natural vegetation and forest, which offsets peat oxidation losses associated with drainage,*
  - *a fall-off in initial peat oxidation rates and a transition to a net ecosystem removal of CO_2 (sink) within 4-12 years after cultivation and planting; the transition rate being dependent on factors such as site productivity, vegetation dynamics, peat depth and type, and climatic influences,,*
  - *all afforestation is assumed to take place on undisturbed peat. However, some afforestation has occurred on previously exploited peatland. In this case, there is a lower initial oxidation rate.*
- *Peatland forest established since 1990 will contribute some 0.6 million tonnes of CO_2 per year to greenhouse gas emission reduction targets over the period 2008-2012.*
- *Although afforested peatlands afford climate change mitigation, peatlands of conservation value should not be afforested.*

COFORD
Dept. Agriculture, Fisheries & Food
Agriculture House, Kildare Street
Dublin 2, Ireland
Telephone: +353 1 607 2487
Email: info@coford.ie
http://www.coford.ie

The greenhouse gas balance of peatland forest

Kevin Black[1] and Gerhard Gallagher[2]

Globally, peatlands contain more carbon (3.0 - 4.6 Pg) than all tropical rainforests combined. In fact, the peatland store is as large as the total amount of carbon in the atmosphere. In their undisturbed state, Irish blanket peatlands continually absorb a small amount of CO_2 from the atmosphere (Koehler et al. 2010), but emit a powerful greenhouse gas, methane. Considering the higher global warming potential of methane (30-fold) compared with CO_2 and losses of dissolved organic matter (DOC) in runoff, the net contribution of peatlands to global warming can be positive, or negative, depending on site conditions, peat type and peatland development stage (Koehler et al. 2010).

Typically, when peatlands are drained for establishment of new forest, methane emissions cease but CO_2 emissions increase substantially, due to the creation of aerobic conditions and oxidisation of organic matter. These processes are

Many peatlands have a high conservation value and should not be afforested.
Photo: Florence Renou-Wilson, UCD.

[1] *Corresponding author: FERS Ltd, Vevay Road, Bray, Co Wicklow/School of Biological and Environmental Science, UCD. Email: kevin.black@ucd.ie.*
[2] *c/o COFORD, Department of Agriculture, Fisheries and Food, Kildare Street, Dublin 2.*

partially offset by the uptake of CO_2 by the growing vegetation, and the accumulation of carbon in woody tissue and litter on the forest floor (Figure 1).

From a national land-use and forest sink perspective, the area of peatland converted to forest between 1990 and 2008, which is compliant with Article 3.3 of the Kyoto protocol, is an important determinant of national forest sink capacity. The COFORD Connects Note on the extent of peatland afforestation in Ireland (Black et al. 2008) shows that ca. 45% of afforestation between 1990 and 2006 was on peat soils (also Black et al. 2008).

Under Article 3.3 of the Kyoto Protocol, all afforestation, deforestation and reforestation activities since 1990 must be reported and accounted for in national greenhouse gas inventories. The time taken for the carbon balance of an afforested peatland area to convert from being a net emission to a net uptake (Figure 1) of CO_2 will vary depending on many factors, including productivity, previous land use, vegetation dynamics, peat depth, peat type and climatic influences.

In this note, the greenhouse gas sink capacity of afforested peatlands is estimated using the national carbon reporting system (CARBWARE, Black et al. 2008) and recent research information.

Greenhouse gas dynamics of peatland forest

The net greenhouse gas fluxes in Figure 1 show different stages of afforested peatland development:

- Undisturbed peatlands are a small CO_2 sink due to uptake by natural vegetation, but can represent a net emission (loss) of greenhouse gasses, expressed as CO_2 equivalents ($CO_{2\ eq.}$), depending on the extent of methane (CH) emissions and loss of stream DOC (Glenn et al. 1993, Regina et al. 2007, Koehler et al. 2010).
- A rapid loss of CO_2 occurs in the first four to eight years after drainage for forest establishment. This is due to a fall in the water table and the creation of aerobic

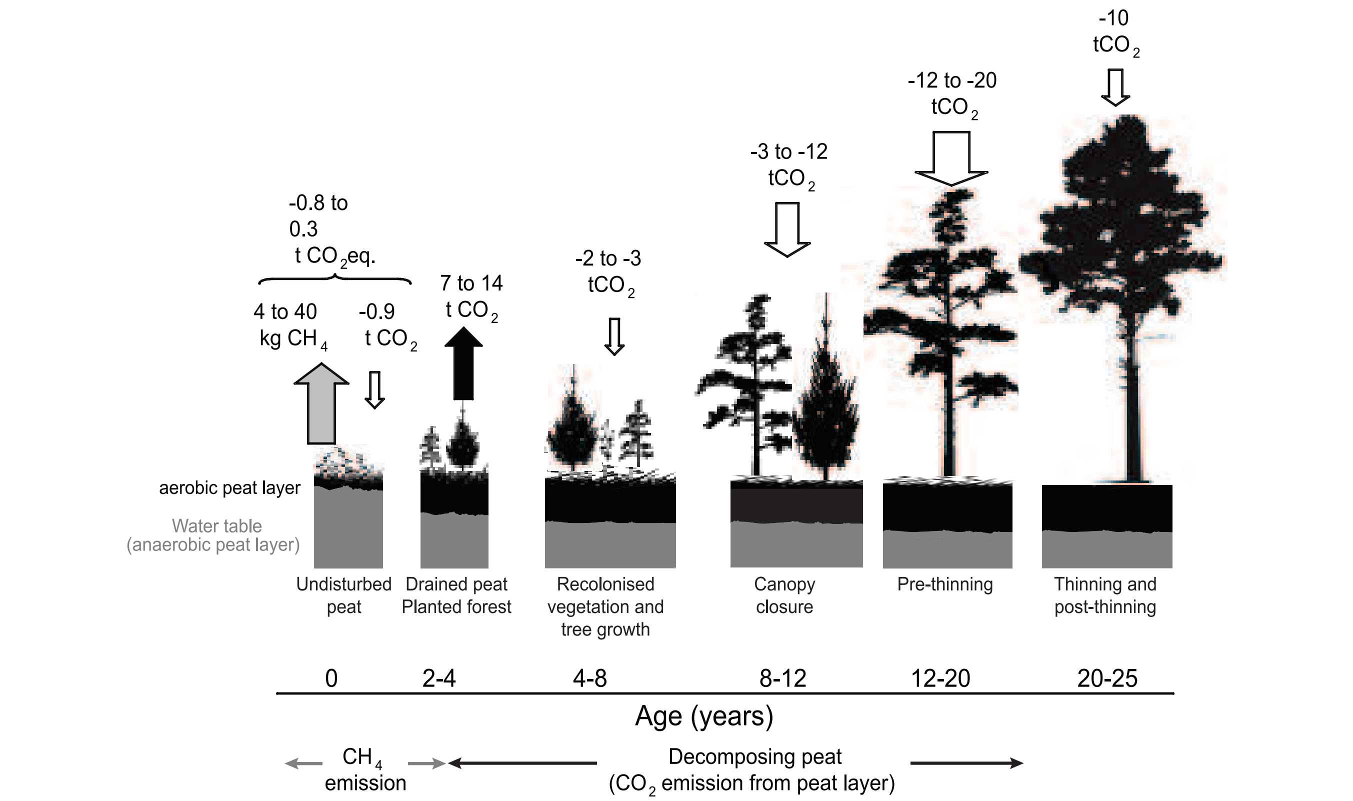

Figure 1: Age-related changes in the greenhouse gas balance of peatlands following afforestation. All values represent an annual flux of CO_2 per ha. Positive values represent a net loss (emission) and negative values represent a net uptake (sink) of greenhouse gas. Values are based on models and published papers for blanket peats (see Glenn et al. 1993, Black, 2007, Hargreaves et al. 2003, Regina et al. 2007).

conditions, where soil carbon is exposed and easily decomposed. However, the production of methane ceases due to the creation of aerobic conditions in the upper peat layers. In some cases methane production may continue, particularly if drainage ditches are not maintained, which may result in a rise in the water table. It is estimated that average loss of peat due to decomposition varies from 1 to 14.6 t CO_2 per ha per year over the first rotation (Hargreaves et al. 2003, Byrne and Farrell 2006, Minkkinen 1999, Alm et al. 1997). Although peat decomposition continues throughout successive forest rotations, it is estimated that the rate of decomposition decreases with time and becomes very small after two to three rotations (Hargreaves et al. 2003, Minkkinen 1997).

- After four to twelve years, photosynthesis and storage of carbon by recolonising vegetation and trees begins to offset the CO_2 loss due to peat decomposition. The amount of CO_2 taken up by the growing forest and storage in biomass and litter increases as the canopy closes, and peaks at ca. 20 t CO_2 per ha per year before the first thinning cycle.
- Harvest and decomposition of harvest residues due to thinning results in a decrease in the net sink capacity in older forests.
- Very little is known about greenhouse gas dynamics following deforestation or abandonment. National research in this area is ongoing; however, it clear that deforestation of these areas will result in a significant loss of CO_2.

Carbon balance models

Age dependent changes in peatland carbon balance were estimated using the current Irish carbon accounting model for Kyoto forest and aforementioned literature (CARBWARE, Black 2007, Gallagher et al. 2004). The area of peatland forests in Ireland was derived from national forest inventory data and other Forest Service data sources (see COFORD Connects Black et al. 2008 and Black 2007). For analysis over a full rotation, the percentage of afforested areas on peatlands for 2006 (29%) was assumed for the period 2008 to 2020. The total afforestation area from 2008 to 2020 was assumed to be 8,000 ha, based on current afforestation figures.

The current CARBWARE model for peats describes changes in the biomass, litter and dead wood pools based on attributes for Sitka spruce (yield class 12) and lodgepole pine (yield class 8) stands according to modified Forestry Commission yield models (Edwards and Christy 1981, Black and Farrell 2006).

Peat decomposition losses were estimated using five published emission factors for blanket peats (Hargreaves et al. 2003, Byrne and Farrell 2006, IPCC 2006, Alm et al. 2007, Minikkenin 1997).

What is the peatland forest sink in relation to the total national Kyoto sink?

- The CARBWARE model suggests that Sitka spruce has the potential to sequester more CO_2 over the first 30 years of the rotation (302-374 t CO_2/ha) compared with lodgepole pine (257-289 t CO_2/ha).
- When the forest carbon balance model was projected using the peatland afforestation statistics, it was evident that post-1990 forest area on peat represents a net loss of CO_2 over the first few years (Figure 2). This initial source (loss) is estimated to vary from 5,000 to 98,700 t CO_2 from 1990 to 1995. However, there is a rapid transition from a net source to a net sink (gain) of CO_2 for the post 1990 afforested area on peatlands after 4 to 8 years.

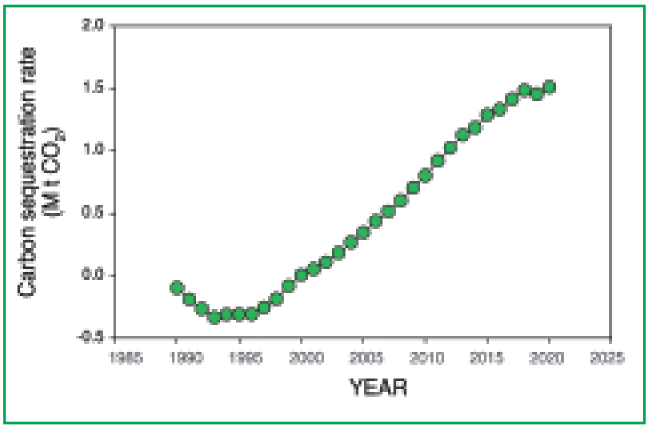

Figure 2: Net emissions (negative) and gains (positive) of CO_2 in afforested areas on peatlands since 1990, projected to 2020 using Forest Service statistics and the CARBWARE model (modified from Black 2007).

- It is projected that the sequestration of CO_2 for the first year of the commitment periods of the Kyoto protocol (2008) is ca. 0.6 M t CO_2 (million tonnes, eq. to a Tg or 10^{12} g). This will represent about 35% of the total post 1990 forest sink in 2008 (Figure 2, Black 2007).

What is the level of uncertainty?

The ecosystem carbon balance of afforested peat soils will vary considerably depending on:

a) the initial peat oxidation rate (implied emission factors),

b) silvicultural management, and

c) species choice and productivity.

Figure 3 shows the potential variation of net CO_2 balance for a yield class 12 Sitka spruce crop planted on blanket peat using published peat oxidation emission factors. Based on this sensitivity analysis, the forest ecosystem would become a net sink (sequester of CO_2) from 4 to 12 years depending on the implied oxidation rate. The net uptake of CO_2 under these scenarios would vary from 365-598 t of CO_2 per ha before clearfell (65 year rotation). The overall uncertainty, based on the coefficient of variation for the five emission factor scenarios, is 23%. The level of uncertainty, associated with peat oxidation emission factors, is lower when compared to variations introduced under different thinning or clearfell management scenarios (coefficient of variation = 35%).

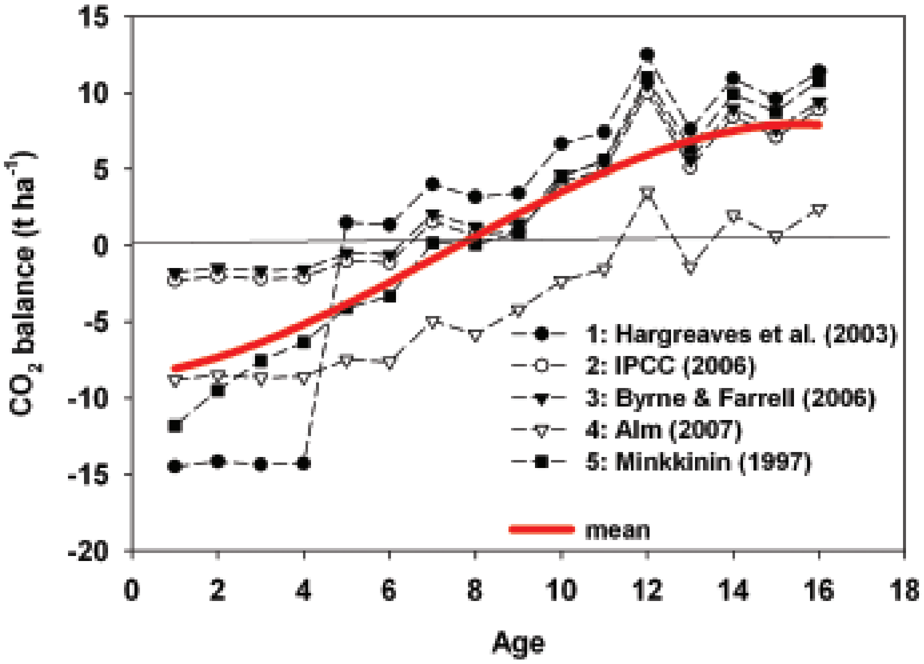

Figure 3: The net the CO_2 balance of a yield class 12 Sitka spruce forest planted on blanket peat assuming five peat oxidation emission factors:
1) 14.2 t CO_2 per ha per year for 4 years (Hargreaves et al. 2003),
2) The IPCC tier 1 default value of 2.4 t CO_2 per ha per year over the entire rotation,
3) a mean emission of 2 t CO_2 ha per year, derived from Byrne and Farrell (2006),
4) a mean emission of 9 t CO_2 per ha per year (Alm et al. 2007) and
5) an exponential decay rate (k= 0.012 t C per year) derived from Minkkinen (1997).
Positive values represent a net uptake (sink) of CO_2.

Conclusions

While it is evident from our results that blanket peats represent the largest proportion of peatland afforesation, studies of CO_2 dynamics on cutaway, fen and basin peats are required, specifically charaterisation of peat oxidation emission factors for different peat types following drainage and afforestation .

The reported Kyoto sink estimates are conservative for the following reasons:

- the models do not include harvested wood carbon storage functions, so emissions due to harvest are over-estimated.
- afforestation does not only occur on undisturbed peatland. Some previously drained peats in agricultural use are converted to forest land. The initial oxidation of the peat soil in this case will be lower than on undisturbed peatland.
- methane fluxes following afforestation are not considered; these are likely to decline rapidly due to drainage.

Given the larger radiative forcing potential of methane compared with CO_2 (ca.30-fold, which means that methane is 30 times more powerful a greenhouse gas than carbon dioxide) and the conservative assumptions used regarding the effect of harvest, suggests that the environmental advantage, in terms of climate change mitigation, of planting peatlands with forest, may be larger than the values reported here.

It is clear that afforestation of peat soils will contribute significantly to reducing national excess greenhouse emissions over the first commitment period of the Kyoto Protocol (Figure 2). In fact, forestry is the only land use, possibly with the exception of some grasslands (Leahy and Scanlon 2004), that can potentially contribute towards climate change mitigation in Ireland.

In contrast to other peatland transitions, such as peat extraction or agricultural activity, afforestation is the only transition resulting in a net uptake of CO_2 in the long term. For example:

- The greenhouse gas emissions associated with the commercial extraction of peat for heating, energy and compost production is estimated to represent a source (emission) of 7-11 Mt of CO_2 per annum (D. Wilson pers. comm.).
- The emission reduction by afforestation on all soil types, since 1990, is estimated to be ca. 2 M t CO_2 in 2007 (Black et al. 2007). Therefore, the greenhouse gas emission reduction associated with afforestation activities is nullified by industrial use of peats.
- Grazing or transition of peatland to grasslands also results represents a significant source of CO_2.

Recommendations

- Initial emissions of CO_2 associated with drainage and forest establishment on peat soils can be reduced by:
    - Planting productive species best suited to peat soils.
    - Maintaining drains to reduce methane emissions and maximise tree growth.
    - Minimising disturbance of natural vegetation to encourage recolonisation.
- If forested peatlands are deforested, the following actions can be taken to minimise further peat decomposition:
    - Block drains to raise the water table and reduce peat decomposition.
    - Minimise soil disturbance to avoid the creation of aerobic conditions, ideal for decomposition of peat.
    - Encourage regeneration of natural vegetation or native woodland species (i.e. montane birch forests) to offset peat decomposition, harvest and harvest residue losses.
- Peatland conservation.

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