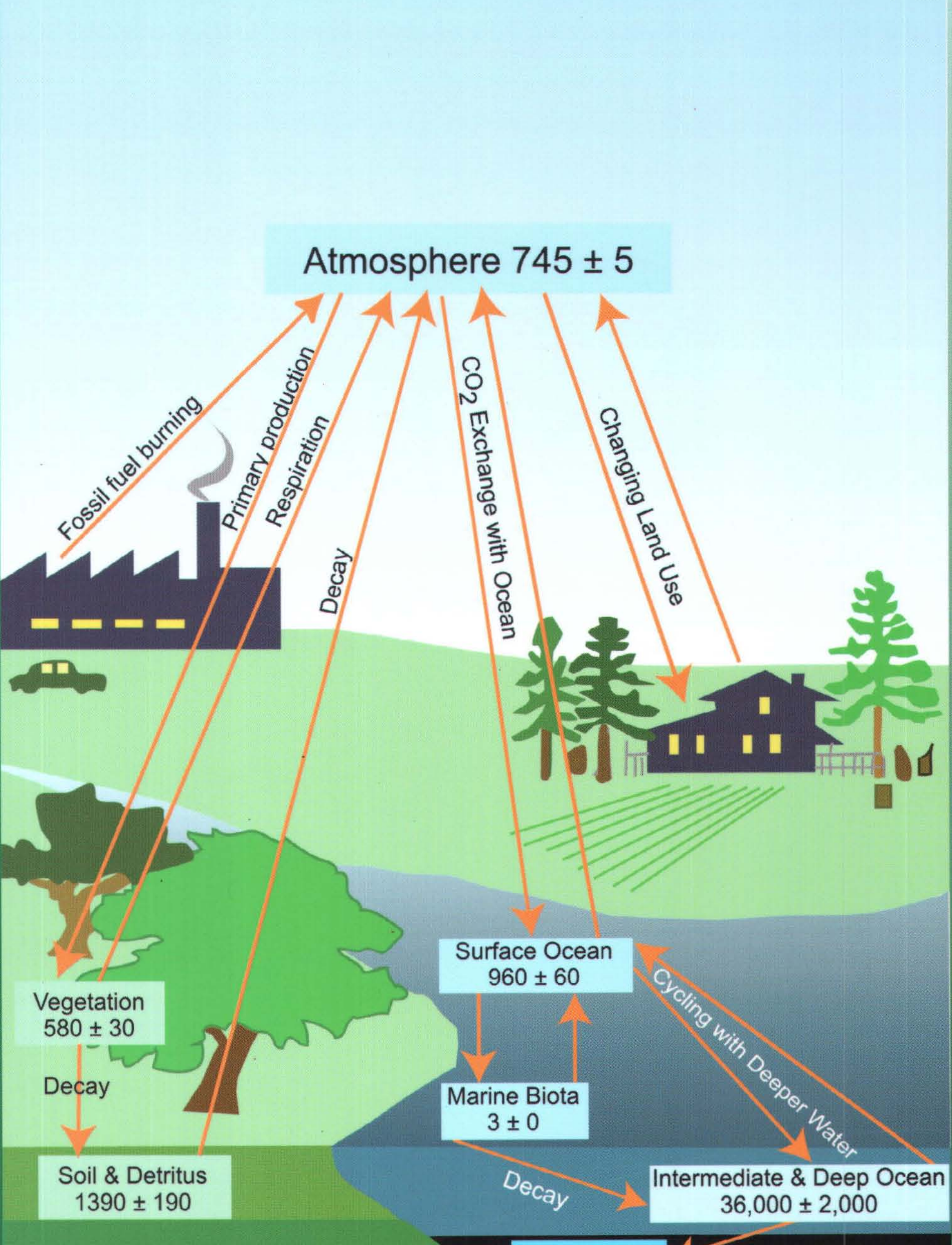
IRISH FORESTRY

JOURNAL
of
THE SOCIETY
OF IRISH
FORESTERS

Forests and Climate Change



Vol. 61 No 1, 2004

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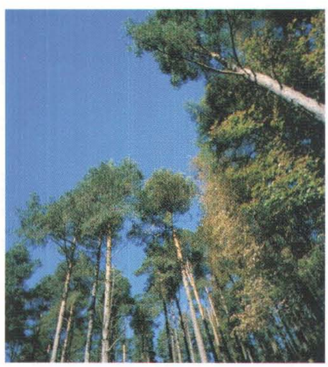

Certification to FSC standards is a voluntary process. Being presented with certification was an important milestone in Coillte's sustainable forest management initiative begun in 1998, the aim of which was to develop a management system that would ensure a correct balance between economic, environmental and social issues in the management of Coillte's forests.

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Cover: *The global carbon cycle depicting exchanges between the biosphere, atmosphere, oceans, and geosphere. In the cycle there are various sinks, or stores, of carbon (represented by the boxes) and processes by which the various sinks exchange carbon (the arrows). Values are in Giga tonnes of carbon.*

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Mission Statement
To lead and represent the forestry profession, which meets, in a sustainable manner, society's needs from Irish forests, through excellence in forestry practice.

Objectives
- To promote a greater knowledge and understanding of forestry in all its aspects, and to advance the economic, social and public benefit values arising from forests.
- To support professionalism in forestry practice and help members achieve their career goals.
- To establish, secure and monitor standards in forestry education and professional practice.
- To foster a greater unity and sense of cohesion among members and provide an appropriate range of services to members.

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- Representing the interests of over 700 members, predominantly professional foresters, but including, through its associate and student membership, a wide cross-section of people involved, or with an interest in, the forest and timber industry.
- Providing an appropriate range of services to its members, e.g. field days, study tours, workshops, lectures and symposia. The Society also publishes *Irish Forestry*, the sole technical publication on forestry in Ireland, a quarterly newsletter *The Irish Forester*, policy position statements and other books of both historical and technical interest. An expansion of services is proposed, e.g. group indemnity insurance scheme.
- Supporting its members by ongoing representation and dialogue at National Government and EU level on forestry issues.
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3. Correct spelling, grammar and punctuation are expected. Nomenclature, symbols and abbreviations should follow established conventions, with the metric system used throughout. Dimensions should follow units with one full space between them, for example 10 kg.

4. Subject to editorial decision, submitted papers will be peer-reviewed. Papers must include an abstract (maximum 250 words) and a list of up to six key words before the main body of the text. Authors are advised to keep papers as concise as possible and no more than 25 pages long (double-spaced, including tables and figures).

5. Where figures are embedded in an article the originals should always be included, along with the information regarding software used to create them. Figures should preferably be saved as graphic files (.eps, .wmf where possible). Avoid .tif, .bmp files and Word picture format. MicroSoft Excel formats, embedded in documents, are acceptable for figures. However, an original hard copy of the figure must also be submitted.

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EDITORIAL

Forests and climate change

Forests are well recognised as a key component of the global climate system, through their function as a store of carbon dioxide, one of the main greenhouse gases. Increases in the concentrations of these gases is now firmly associated with global warming trends. Removal of forest cover has of itself contributed a significant part of the 30% increase in carbon dioxide concentrations that have occurred since the early 1700s, from 280 to about 360 parts per million. Even today well over a third of carbon dioxide emissions are attributable to deforestation, and in many developing countries far exceed those from fossil fuels.

Tackling climate change is a huge challenge; sceptics would say an impossible one. The international community, in the form of the United Nations Framework Convention on Climate Change, has been wrestling with the problem for close on a decade. What it came up with at Kyoto was a proposal to reduce greenhouse gas emissions by a very modest 5%, based on 1990 levels. Despite this number being far below the 25-30% level many feel is necessary to halt climate change, countries such as Australia and the US have had second thoughts, and have effectively turned their back on the Protocol. Ireland, along with other EU Member States has ratified the agreement, and is firmly committed to meeting its target of keeping emissions at the 1990 level, plus 13%. however, we are well over target, some 30% over the 1990 level. Some analysts have estimated that to achieve compliance annual emissions will have to be reduced by over 9 million tonnes of carbon dioxide per year by 2008. Compliance will come at a cost; and achieving it will rely on a number of measures including forestry.

In the Kyoto negotiations forests were introduced at a late state in the process, as a bargaining chip by large countries. They argued that net uptake of carbon dioxide by forests (and other land uses) was a legitimate way of reducing greenhouse gas concentrations. While this is patently true, carbon stored in trees and other vegetation can also be lost back to the atmosphere through fire, other natural events, and harvesting. This is one of the reasons for the protracted sink negotiations that continued through from Kyoto in 1997 up to 2001, when the Marrakesh Accords clarified most of the main policy issues, and the rules to safeguard against this so-called sink reversal.

Detailed rules and guidance in relation to sinks have followed in the interim, with the final round of negotiations set for December in Buenos Aires. Many hours of negotiation time have been spent on defining the rules and in devising good practice. A good example of the scale of effort involved is the Intergovernmental Panel on Climate Change Good Practice Guidance for Land Use, Land-Use Change and Forestry launched in June. It runs to over 550 pages, and outlines best approaches to dealing with the land use activities permitted under the Marrakesh Accords.

So forestry is now an integral part of the climate change process and is likely to remain so. Too many countries have a serious national interest in sinks, either in using them to make compliance, or in avoiding penalties that arise as a result of deforestation, to drop sinks from the system. It also makes good sense to rebuild the global terrestrial carbon sink, if for no other reason than to buy time until emission reduction measures start to make serious inroads. Another key reason is that sinks offer a way for developing countries to become involved in the climate process. At the moment countries such as Brazil, China and India have no emission reduction commitments, even though their emissions are climbing rapidly as their economies expand.

However they still have a long way to go catch up on the US. Although it has withdrawn from the Kyoto protocol, it may at some stage in the future take a decision to make legally binding emission reduction commitments. Whether this will be as part of renegotiated Kyoto or a new package is unclear. What is clear is that it will only be on the basis of the inclusion of sink activities. The US has always been one of the strongest advocates of using sinks to achieve reductions in greenhouse gas concentrations.

Constraining the use of sinks has exercised many countries in the negotiation processes. Green groups and environmental NGOs have also been highly sceptical of their role in addressing climate change, seeing them as an easy option that reduces the onus on countries to reduce emissions. Arising from these considerations the role of sinks is highly circumscribed, with caps on forest management and the use of sinks in developing countries.

Ireland, together with a relatively small number of developed countries, has a significant national afforestation programme. Since 1990 this has resulted in 226,000 ha of new forest being planted. All of this area is eligible for the issuance of removal units (RMUs – each RMU is equivalent to one tonne of carbon dioxide). The plan is that these units will be used as part of a range of measures to achieve compliance with Ireland's emission target. COFORD and a number of agencies are cooperating in putting in place the system to estimate RMUs and track the areas for which they are issued. As well as calculating carbon sequestration the system will track deforestation, as losses as well as gains must be reported. This system will also have to track harvesting, again removals are treated as a carbon loss to the system.

One must ask what benefit should accrue to the forestry sector from its contribution to achieving Ireland's international obligation under Kyoto? First of all the role of the afforestation programme should be recognised and supported by the state into the future. It is probably the only land-based activity that will positively contribute to achieving compliance with the Kyoto target. Maintenance and enhancement of carbon stocks is therefore a key issue; sustainable forest management has the key role here and deserves state support, on the basis that it is the state which will benefit from compliance with Kyoto targets.

Looking to the longer term there is a natural limit to the extent that land-based activities can contribute to climate change. Emission reductions are the only effective long-term solution. Switching to renewables is the technological answer but they are not cost competitive when compared with oil and gas, at least not using a simple energy return per unit of capital employed comparison. But there are risks associated with fossil fuels, apart altogether from climate change issues. Over reliance is one obvious risk – 98% of Ireland's primary energy requirement comes from fossil fuels. EU policy is to reduce reliance on fossil fuels and have renewables supplying 12% of total energy requirements by 2010, and 20% by 2010. Ireland's poor record on the renewables front will have to be seriously addressed to achieve these targets.

The forestry sector must take a leading role as an advocate and implementer of renewable energy policy. It has a rapidly growing resource coupled with considerable know-how in cost effective harvesting systems. What is lacking is an effective national policy to support and develop biomass to a stage where it can contribute 10 to 15% of national energy requirements. This can be done over a 15-year timeframe, given continued investment in the afforestation programme and innovative policies for delivery of renewable energy.

The role of forests in the global carbon cycle and in climate change policy

Kenneth A. Byrne[a] and Carly Green[b]

Abstract
It is now widely accepted that increasing levels of greenhouse gases in the atmosphere are altering the Earth's climate system. Forests store and sequester vast amounts of carbon and are therefore a key component of the global carbon cycle. Understanding the nature of that contribution is vital to understanding current and future climate trends. The ability of forests to sequester atmospheric carbon led to their inclusion in the Kyoto Protocol as a means to mitigate greenhouse gas emissions. This paper discusses the role of forest in both the global carbon cycle and climate change policy. The various means by which forests can contribute to reduction of greenhouse gas emissions are also discussed.

Key words: Carbon sequestration, forest ecosystems, Kyoto Protocol

Introduction
The global carbon (C) cycle is a vital component of the Earth's system and consists of various reservoirs (stocks), and the dynamic transfer of carbon between them (fluxes). Both internal, i.e. photosynthesis and respiration, and external forces, i.e. environmental and human disturbance, can cause each of these reservoirs to act as sources and sinks of carbon at various temporal scales. The largest reservoirs of carbon include the oceans, fossil fuel reserves, the terrestrial environment and the atmosphere. Since the onset of the industrial revolution, the burning of fossil fuels has resulted in a large anthropogenic flux of C to the atmosphere. It is widely accepted that this shift in the C balance has largely contributed to the onset of global climate change.

Identification of options for mitigating atmospheric C concentrations and development of global climate policy measures has lead to the requirement to report forest related activities under the United Nations Framework Convention on Climate Change (UNFCCC) and subsequently to the Kyoto Protocol, should it enter into force.

Such reporting focuses on changes in carbon stocks following afforestation, reforestation and deforestation activities as well as forest management practices. Analysis of current climate change policy indicates a focus towards relatively cheap carbon storage through land use practices. However, available land for increasing carbon stocks through human induced, i.e. afforestation/reforestation activities, is a limited resource and subsequently so too is the potential of vegetation management as a mitigation measure. Alternatives which can provide long-term solutions are the

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utilisation of biomass through the direct substitution of fossil fuel intensive products and energy generation.

Global carbon cycle and climate change

From approximately 420,000 years ago until the onset of the industrial revolution (circa 1750) the Earth's climate system acted within a limited temperature range which was influenced by the relatively stable concentration of carbon dioxide (CO_2) and methane (CH_4) in the atmosphere (Petit et al. 1999). GHGs occur naturally in the atmosphere and absorb infrared radiation that the Earth re-radiates to space. This phenomenon maintains the Earth's temperature within the delicate range required to sustain life. However, atmospheric CO_2 levels are now nearly 100 ppm higher than at any time during the previous 420,000 years; concentrations of CO_2, CH_4 and N_2O in the atmosphere have increased by 31, 150 and 16% respectively since 1750[1] (IPCC 2001). Increases in these gases are primarily driven by human activities such as burning fossil fuel, agriculture and land use change. It is generally accepted that these increases are causing a shift in the Earth's radiative balance with consequent effects on the global climate system. The Intergovernmental Panel on Climate Change (IPCC) estimated that during the 20th century the global average surface temperature increased by about 0.6 °C, snow cover and ice extent decreased, sea level rose 0.1–0.2 m and rainfall increased in mid- and high latitudes These changes are likely to continue with the global average surface temperature expected to increase by 1.4–5.8 °C during 1990-2100. Further changes in sea level and weather patterns are expected (IPCC 2001).

Forests and the global carbon cycle

About half of the CO_2 emitted by fossil fuel combustion and tropical deforestation accumulates in the atmosphere. The rest is taken up by the oceans and terrestrial biosphere (Bousquet et al. 2000, Prentice et al. 2001). It is likely that forests account for a large portion of this biospheric uptake, since they are estimated to contain 77% of the carbon contained in vegetation and 39% of that stored in soils (Bolin et al. 2000). According to Prentice et al. (2001) (Table 1), during the 1980s the Earth's terrestrial ecosystems were a small net C sink (0.2 Pg C $year^{-1}$), the size of which increased during the 1990s to 1.4 Pg C $year^{-1}$.

Despite this overall increase in C uptake changes in land use (e.g. afforestation, reforestation, deforestation, forest management, fire and agriculture) resulted in the average annual C release of 2.0 (±0.8) Pg during the 1980s and 2.2 (±0.8) Pg during the 1990s (Table 1). Included in these estimates is the accumulation of C as a result of afforestation and reforestation. However, the combination of the average net terrestrial sink for the 1980s (0.2 Pg $year^{-1}$), with the average annual net source due to land-use change for the same period (2.0 Pg $year^{-1}$), suggests the existence of an additional sink, accounting for on average 2.2 Pg $year^{-1}$ during the 1980s. During the 1990s this additional or residual sink increased to 3.6 Pg $year^{-1}$. This sink is calculated as

[1] Although the principal GHGs are CO_2, CH_4 and N_2O, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6), play a significant but smaller role.

Table 1. *The global carbon budget (modified from Prentice et al. 2001) units are Pg year^{-1}).*

	1980s	*1990s*
Fossil fuel emissions	5.4 ± 0.3	6.4 ± 0.6
Atmospheric increase	3.3 ± 0.1	3.2 ± 0.2
Oceanic uptake	-1.9 ± 0.5	-1.7 ± 0.5
Net terrestrial flux	-0.2 ± 0.7	-1.4 ± 0.7
Land-use change	2.0 ± 0.8 (1.2-1.8)	2.2 ± 0.6
Residual terrestrial flux	-2.2 ± 1.1	-3.6 (highly uncertain)

Source: Houghton (2003).

differences between other components in the global C budget and therefore if emissions due to land-use change were lower the residual sink would also be lower. Increased understanding and estimates of the known C sinks within the global budget may enable the magnitude of this residual sink to be reduced.

The forest carbon cycle

The C cycle in forests is characterised by a number of 'pools' and 'fluxes'. Pools are sites of C accumulation such as above- and below-ground biomass, litter on the forest floor and organic matter in the soil. Each pool contains a quantity of C that is referred to as the 'stock'. C is transferred between pools by many different processes including photosynthesis, respiration and decomposition. The amount of C transferred into or out of a stock is known as a 'flux'. The net flux of C between a forest and the atmosphere is determined by the balance between C uptake as a result of photosynthesis and C loss as a result of respiration by trees, both above- and below-ground, and decomposition of soil organic matter. Therefore if C uptake exceeds loss the forest is a 'sink' for atmospheric C. Conversely, if loss exceeds uptake the forest is a 'source' for atmospheric C. The forest C cycle extends beyond the forest boundaries when timber is removed from the forest during harvesting to be used in forest products, or biomass is removed to generate energy.

Forests as sinks and sources of carbon

In common with all green plants, trees capture CO_2 from the atmosphere through the process of photosynthesis. Initially sugar molecules are formed which then combine to produce cellulose, in addition to lignin in the case of woody plants. This growth and maintenance of living material has an energy cost as a result of which much of the CO_2 captured through photosynthesis is lost through respiration. The remaining C is added to the various components of the biomass C pool such as foliage, roots, stem and branch biomass creating a sink. Processes such as litterfall, litter decomposition and root turnover can add C to the soil pool.

The magnitude of a forest C sink can be affected by many factors such as changes in land use, soil type, forest management activities such as harvesting and fertilisation, changes in climate, nitrogen deposition, disease outbreaks and fire. In the initial establishment stages of the forest growth cycle a net carbon loss (particularly from soil) could be experienced as a result of site preparation. Following this initial growth phase a rapid uptake of carbon is experienced, which subsequently levels off as the stand reaches maturity. Finally the forest reaches the mature growth stage and the carbon is in steady state (neither a source or a sink) with accumulation associated with new growth balanced by mortality and disturbances (Matthews and Robertson 2002). Forest stands managed for commercial production experience periodic harvesting prior to maturity and generally have lower carbon stocks than old growth stands that are not harvested. The longer-term C stock and its status as a source or a sink depends on a balance between the impacts of harvesting and the rate of forest regeneration.

Afforestation generally results in the creation of a sink in that it increases C stocks on previously non-forested land. This is particularly the case if such land was previously under intensive management (e.g. arable crop production) and had depleted soil C stocks. However, drainage and afforestation of C rich soils such as peatlands may accelerate decomposition of soil C. Such losses may exceed C uptake by biomass (Hargreaves et al. 2003) at least in the initial stages of crop growth resulting in the land area being a C source.

International negotiations and the Kyoto Protocol

The first global attempt to deal with climate change was formalised with the United Nations Framework Convention on Climate Change (UNFCCC), agreed at the Earth Summit held in Rio de Janeiro in 1992. Its goal is *the stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner*. Ireland ratified the UNFCCC in 1994. As a Party it is required to develop, periodically update, publish and make available to the Conference of the Parties (COP) national inventories of emissions by sources and removals by sinks of GHGs and to promote the conservation and enhancement of sources and sinks of all GHGs. Forests represent one sector for which a national inventory is required.

In recognising concerns about climate change the UNFCCC provided an essential first step in the move towards tackling the problem. However, its objective could only be achieved with the establishment of legally binding targets to reduce GHG emissions. This was accomplished at the Third Conference of the Parties (COP3) in December 1997, when the Kyoto Protocol to the UNFCCC was negotiated. Its salient features are:

- 1990 is the base year against which all emission reduction commitments are calculated.
- 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 committed to a reduction of 8%. The Protocol could only enter into force when ratified by at least 55% of Annex I countries, which cumulatively represent at least 55% of global GHG emissions.
- The Protocol made provision for the use of C sequestration by land use, land use change and forestry (LULUCF) as a means to offset GHG emissions.

In recognition of the differences in economic development between Member States, the European Union negotiated an agreement to share its reduction commitment. Under this agreement Ireland is committed to limiting its GHG emissions to 13% above 1990 levels by the first commitment period. The fact that emissions in 2002 were 29% above 1990 level (EPA 2004) underlines the magnitude of this challenge.

The use of sinks was a controversial aspect of the negotiations leading up to the Kyoto Protocol. On the one hand, sinks play a significant role in the global C cycle and are a relatively inexpensive means of potentially achieving emissions reductions. However an over dependence on sinks may undermine attempts to reduce fossil fuel emissions. This could reduce the incentive to develop the kinds of technologies that are needed to achieve further reductions and therefore increase the cost of reductions in the medium to long term. On the other hand, it could be argued that lower compliance costs in the first commitment period could make countries more willing to accept further reductions in subsequent commitment periods.

Although LULUCF activities were included in the Kyoto Protocol, the use of sinks is limited to specific activities. Article 3.3 refers to *...net changes in greenhouse gas emissions by sources and removals by sinks resulting from direct human-induced land-use change and forestry activities, limited to afforestation, reforestation and deforestation since 1990, measured as verifiable changes in carbon stocks in each commitment period ...* Article 3.4 refers to *...additional human-induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural soils and the land-use change and forestry categories ... A Party may choose to apply such a decision on these additional human-induced activities for its first commitment period, provided these activities have taken place since 1990.* Other articles that include provision for the use of forest sinks are Article 6 which deals the trading of emission reduction units and Article 12 – the clean development mechanism (CDM) which deals with emission-offset trading projects between developed (Annex I) and developing countries (non-Annex I).

While the Protocol established targets for the reduction of GHG emissions and identified mechanisms by which this could be done, it did not define rules and modalities for achieving such reductions. For instance the Protocol did not define reforestation so the term was open to interpretation. Reforestation has been variously defined as the restocking of forest sites after clearfelling or as the establishment of forest on land that had been forest at some time in the past but has been since converted to another land use. The choice of definition has important implications for the manner in which Parties may account for C stocks and stock changes in their forests. Final agreement on the way forward was achieved at COP7 in Marrakesh in November 2001 with the completion of the 'Marrakesh Accords' (MA).

The MA include a number of definitions. 'Forest' is a minimum area of land of 0.05-

1.0 ha with tree crown cover (or equivalent stocking level) of more than 10-30 per cent with trees having the potential to reach a minimum height of 2-5 metres at maturity *in situ*. 'Afforestation' is the direct human induced conversion of land that has not been forested for a period of at least 50 years to forested land through planting, seeding and/or the human-induced promotion of natural seed sources. 'Reforestation' is the direct human-induced conversion of non-forested land to forested land through planting, seeding and/or the human induced promotion of natural seed sources, on land that was forested but had been converted to non-forested land. For the first commitment period, reforestation activities will be limited to those lands that did not contain forest on 31 December 1989. 'Deforestation' is the direct human-induced conversion of land to non-forested land.

One of the most contentious aspects of the negotiations was the means by which Parties may apply Article 3.4 to forest management. In the absence of a clear methodology a limit was set to the amount of credits a Party may claim.

The MA place no cap on the amount of credit a Party (e.g. Ireland) may claim under Article 3.3. As stated above, forest management is one of the eligible activities under Article 3.4 and the amount of credit Ireland can claim has been capped at 50,000 t C $year^{-1}$ during the first commitment period. Parties should account for changes in the following C pools: above-ground biomass, below-ground biomass, litter, dead wood, and soil organic matter. A Party may only choose not to account for a given pool providing it can show that the pool is not a C source.

As stated, the UNFCCC required that Parties develop GHG inventories. Guidance in the preparation of inventories is provided by the *Revised 1996 IPCC Guidelines for National Greenhouse Inventories* (Houghton 1997). However, the Kyoto Protocol has additional reporting requirements not covered in these Guidelines. For instance, the human induced activities under Articles 3.3 and 3.4 have particular requirements on issues such as, identification of areas, temporal and spatial boundaries, avoidance of double counting, inclusion of C pools and definitional differences in LULUCF activities to the UNFCCC. In order to assist this the IPCC has prepared a report on *Good Practice Guidance for Land Use, Land-Use Change and Forestry* (IPCC 2004). This provides guidance to Parties as to best report sources and sinks in the LULUCF sector whilst making the most use of available resources and limiting uncertainty. While the report provides default data and methods, Parties are encouraged to apply nationally specific data where possible.

Alternatives to sequestration in the mitigation or reduction of GHG emissions

The Kyoto Protocol focuses on the use of forests as a C sink, mitigating increases in atmospheric CO_2 concentrations. It has been suggested that such a focus on cheap carbon storage may impede the development of bioenergy and poses no long-term solution for mitigation of GHG emissions (Schlamadinger et al. 2001) As previously established, forests have a finite capacity to remove CO_2 from the atmosphere. Under current conditions there may be potential to promote carbon sinks globally in the relative short term (next 100 years or more) but this will be limited by C stocks in vegetation and soils reaching equilibrium and the limited availability of land to create new C sinks. Various estimates have been suggested regarding the potential global C sink capacity generated through vegetation management. Green and Byrne (2004) report a range between 60 and 87 Gt C by 2050, or 14-20% of the projected fossil fuel emissions. If reducing GHG emissions is the objective, additional mitigation measures will need to be adopted.

Other than afforestation, carbon stocks in forest and forest products can be managed to influence C stocks and fluxes and therefore GHG emissions.

Forest management practices undertaken in existing forest in order to conserve and enhance existing C stocks can include forest regeneration, forest fertilisation, pest management, fire management, harvest quantity and timing, low impact harvesting (in terms of quantity and timing of removal in addition to site disturbance) and reducing forest degradation (Sampson et al. 2000). While these practices can lead to increased C storage it should be remembered that forest management techniques which aim to increase C stock needs to be compatible with the wider management objectives. For example, reduced thinning intensity may lead to greater C stock at stand level. However, this would not only have an impact upon the timber quality and range of assortments produced at the time of final felling, but would also, if applied on a large scale, affect the processing sector which utilises such thinnings.

If, however, the objective goes beyond that of providing sinks for emissions resulting from fossil fuels and becomes one of permanently offsetting emissions by replacing fossil fuel intensive products and technology then forest can possibly provide a much longer-term solution.

Global C cycle (Kirschbaum 2003) and climate policy modelling (Gielen et al. 2002) of use options for forest biomass indicate that longer term planning, i.e. 50 to 100 years, favours the use of biomass for energy. Global estimates of the potential for GHG emissions avoidance through bioenergy initiatives range from 2.0 to 6.2 Gt C year^{-1}, or 17% to 54% of projected emissions from fossil fuels.

Forest management residues including branches, tops and small diameter stems from thinning and harvest of commercial plantations are an under-utilised source of biomass, with a potential commercial value. Full utilization of thinnings, which may represent approximately 25% of the biomass produced, permits energy recovery from a resource that may otherwise decay on the forest floor. In both cases the carbon in the biomass is returned to atmosphere, but where bioenergy is produced, greenhouse mitigation benefit is obtained from displacement of fossil fuel emissions (IEA Bioenergy Task 25 1998, Matthews and Robertson 2002, Green and Byrne 2004).

Indirectly, biomass could also displace fossil fuels by providing substitute products for energy intensive materials such as steel, aluminium and plastics. Current estimates of the global C stock in the wood products range between 2 – 8 Gt C (Broadmeadow and Matthews 2003, Kirschbaum 2003, Green and Byrne 2004). Although increasing this pool through product substitution will be dependent on practical and technically feasible applications at a local to regional level, there is a large potential to replace a range of materials in domestic and industrial applications.

The potential carbon sink in wood products is estimated to be relatively small compared to the carbon sink in living vegetation and biomass, or compared to the potential of wood products to displace fossil fuel consumption. However, utilising the full range of options may enable such products to play a significant role.

Conclusions

Forests play a significant role in combating climate change. Release of the carbon contained in the world's forests would be sufficient to raise atmospheric CO_2 levels to more than 1000 ppm and lead to a rise in temperature of 5-8 °C (Broadmeadow and Matthews 2003). Conserving and protecting global forests, and therefore their C stocks, is an integral component of efforts to combat climate change. Current global climate change policy has an emphasis on increasing carbon stocks through land use change and forestry activities. It is important to recognise that forests are not capable of mitigating all greenhouse gas emissions. Although policy has identified a relatively cheap C sink potential with a short term implementation period, increasing C storage in existing forests is limited by land availability and the fact that such sinks reach equilibrium in the short term. With this focus on cheap carbon storage, current policy has the potential to impede the development of bioenergy and poses no long-term solution for GHG emissions (Schlamadinger et al. 2001). However, efforts taken now to enhance and expand forest areas will assist efforts to mitigate climate change in the short term to medium term, increasing the biomass resource and perhaps mitigation options available to future generations and when practiced in the context of sustainable forest management, bring multiple benefits to society.

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The potential impact of climate change on Irish forestry[1]

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Abstract

The Irish climate is projected to change over the next century. The long-term nature of forestry means that planning is essential if foresters are to practice sustainable forest management during and beyond this period of change. International models projecting the potential impact of climate change on forestry have improved significantly over the last decade, but are still a long way short of accurately modelling the complexities of forest ecosystems. Although it is generally accepted that rising temperatures and CO_2 concentrations will promote increased growth rates, it is uncertain to what extent this growth will be limited by water and nutrient availability, greater difficulties in forest establishment and increased risk from pests, diseases and forest fire. Irish forests are predominantly commercial plantations established on sites deemed either unsuitable or marginal for agriculture. They may therefore respond differently to climate change than native or semi-natural forests. The current programme for the expansion of Irish forestry may require adjustment to account for the prospect of climate change. Research programmes should also be initiated to investigate how climate change may affect the productive and ecological functions of Irish forests.

Introduction

The Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) has reported a global average surface temperature increase of about 0.6°C since the start of the 20th century. The report also claims that it is very likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record since 1861. The IPCC has projected that the scale and rate of climate change for the 21st century will exceed the changes observed during the 20th century. Confidence in the ability of models to predict future climate has increased. There is broad scientific consensus that anthropogenic influences will continue to affect atmospheric composition and climate throughout the 21st century and that these changes will persist for many centuries.

Sweeney and Fealy (2001) used high-resolution statistical downscaling techniques in forecasting future climate scenarios for Ireland. Milder winters and warmer summers are

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forecasted with general temperature increases of 2 to 3°C expected by mid-century (Figure 1). With the exception of low lying areas in the north-east, east and south-east, winter precipitation is expected to increase by up to 25 mm per winter month. Summer precipitation is expected to decrease on 1961-1990 levels along a north-west to south-east gradient (Figure 2), with little change in the north-west but potential drought problems in the east and south-east. However, there is less reliance on forecast data for precipitation. In the projections of future climate change made by the IPCC (IPCC 2001), increased frequency of strong wind and storm events are forecasted for the North-East Atlantic and Western Europe. The (Irish) National Climate Change Strategy (Department of the Environment and Local Government 2000) projects an increase of approximately 12.5% of CO_2 equivalent greenhouse gas emissions over a 10-year period in Ireland.

The growth of trees and forests is highly influenced by climate. Indigenous forest ecosystems evolve in response to changing biogeochemical conditions. Because they are adapted to local climates, changed conditions are likely to impact on their future growth and wood output (Joyce and Nungesser 2000). In many regions where native species are used in the establishment of plantations, great care is taken in the selection of seed source, in order to match it to local climatic conditions. In countries such as Ireland, where exotic species are widely used, foresters pay close attention to site suitability, focusing on soil type and the prevailing micro-climate, both of which are heavily influenced by overriding climatic conditions. Their decisions are also influenced by potential markets into which they hope to sell products.

Because of the longevity of trees and forests, questions have been asked as to whether there will be enough evolutionary response time for forest ecosystems to adapt to severe climatic change (Andrasko 1990). In planning for the future, foresters should select species that will perform optimally over a full rotation. Currently, this embraces a period of 40 to 50 years, but it is doubtful if this is an ecological optimum, and the possibility that rotations may be increased in the future must also be considered. It is therefore essential for foresters to know what the likely changes in climate will be and what potential impact these changes will have on trees and forests.

Forest managers are increasingly responsible for the sustainable management of the forest ecosystem as a whole (Farrell et al. 2000). This is a considerably more complex task than fulfilling a single objective of sustainable wood production. Similarly, modelling forest ecosystems as a whole is far more complex than modelling wood production. Most authors dealing with the subject of climate change and its potential effects on forestry emphasise the limitations associated with their research. However, there are definite trends in the body of research carried out to date and there is broad agreement on many of the conclusions drawn so far.

Modelling forest growth

Forest planning, whether it is based on silviculture or economics or whether it is carried out on a local, regional or national basis, is dependent on being able to forecast or model forest growth at stand level. Obviously, from a forest planning point of view, it would be useful to accurately model future changes to the forest ecosystem as a result of changing environmental and specifically climatic conditions. Currently in Ireland, forest growth is modelled in one of two ways, which are best described by García (1988) as static or dynamic.

Static growth models attempt to predict changes over time in key production parameters, such as mean volume and mean diameter at breast height, based on reference to similar stands closely studied over extended periods. Historically in Ireland such tables, in the form of the Forestry Commission Management Tables (Johnston and Bradley 1963), have been used by foresters. These models are dependent on the maintenance of a *status quo* with regard to the macro environment in which the forests grow and the management regime applied. In the context of climate change they may therefore not be reliable in forecasting future productivity of Irish forests.

For many reasons, including those outlined, the Irish forestry sector has recently developed dynamic growth models for the important commercial species. Dynamic growth models account for changing management practice and environmental conditions over a forest rotation. Dynamic models currently used in Ireland do not use direct measurements of changes in the environment itself. Nor do they measure or directly take account of changes to the forest ecosystem (e.g. available soil nitrogen, available moisture, soil pH, etc.), which greatly influence the productive potential of the timber crop. However, the effect of a changing environment is reflected in measurements taken of the wood production variables over time. Unlike static models, dynamic models allow for current measurements of such variables to form the baseline from which future growth is projected; there is no requirement to fit data to static tabulated values. In this way the rate and effect of environmental change is implicitly taken into account. Hence, these models are a step in the right direction in recognising the need for a dynamic approach to growth modelling.

Unfortunately, none of the growth models currently used by Irish foresters attempt to model aspects of the forest ecosystem other than critical forest production variables such as height, volume and diameter. There are however many uncertainties associated with the modelling of a whole ecosystem and its vulnerability to climate change. Work is proceeding on models based on ecosystem processes (termed process-based models) in several countries, although they are still in the early stage of development. An initial attempt has been made in the application of a process-based model to forest growth in Ireland (Goodale et al. 1998), but no developmental work is currently being conducted here.

Potential primary effects of climate change

Potential primary effects are those changes in variables such as carbon dioxide (CO_2) enrichment, higher temperatures, stronger winds or lower rainfall, that may have an effect on tree or forest growth.

Increased CO_2 level

There is well-documented evidence of rising atmospheric concentrations of greenhouse gases, notably CO_2 (the dominant anthropogenic greenhouse gas) over the last century (IPCC 2001). On a global scale, the IPCC reports an average rate of increase of atmospheric CO_2 concentrations of 0.4% per year (IPCC 2001); these are projected to double over the next 100 years. The National Climate Change Strategy (Department of the Environment and Local Government 2000) projects a 12.5% increase in greenhouse gas emissions over a 10-year period from 2000 to 2010.

As CO_2 is the carbon source for photosynthesis, plant growth is highly influenced by CO_2 levels in the atmosphere. Rising CO_2 concentrations, in addition to influencing other climatic factors, are therefore likely to have a direct effect on tree growth. CO_2 is limiting to the rate of photosynthesis in C_3 species[2] (Breymeyer et al. 1996). This is thought to be particularly the case in a mature forest environment, where tree canopies are tightly bunched and air circulation is restricted (Daniel et al. 1979). Increased CO_2 concentrations would therefore be expected to stimulate tree growth, through what has become known as CO_2 fertilisation, and this has been proven in experiments such as those on oak (Broadmeadow 2000) and across a range of woody plants (Ceulemans and Mousseau 1994). In a review of current knowledge of tree and forest functioning in an enriched CO_2 atmosphere, Saxe et al. (1998) report that a number of recent studies indicate the potential for a persistent enhancement of tree growth over several years.

However, Joyce and Nungesser (2000) and Saxe et al. (1998) both point out that most experimentation has been carried out using seedlings or juvenile trees. It may be too early therefore to say whether increased growth due to CO_2 fertilisation is sustained over a full rotation or in a mature forest environment. Indeed, the capacity of ecosystems for additional carbon uptake may be limited by availability of nutrients and other biophysical factors (IPCC 2001). Difficulties arise in some scenarios in attributing growth responses to single parameters. This is a point underlined by Andrasko (1990) who claims that, because very little work has been done in situ on forest or other natural communities over extended time frames, the net effect of CO_2 enrichment, combined with forest decline from climate change and air pollution, remains uncertain. Despite this, recent studies by Spiecker et al. (1996) found that growth rates in European forests have increased and this has been partly attributed to climate change and nitrogen deposition.

Most research conducted on the impact of elevated CO_2 on water-use efficiency concludes that stomatal conductance from leaves will be reduced and that this will lead to diminished transpiration rates, thus leading to greater water use efficiency (Saxe et al. 1998). The stomata of conifers tend to respond less to elevated atmospheric CO_2 than those of broadleaves (Jarvis 1989, cited in Breymeyer et al. 1996). Despite this, Townsend (1993) reported a doubling of water use efficiency in Sitka spruce (*Picea sitchensis*) seedlings when CO_2 concentrations were doubled. This may be offset by increased leaf area associated with CO_2 fertilisation (Saxe et al. 1998).

Increased temperature

The IPCC report in their Third Assessment Report that global average surface temperature has increased by 0.6 ± 0.2°C since the late 19th century (IPCC 2001). The

[2] C_3 species are those in which the first product of photosynthetic CO_2 assimilation is a 3-carbon compound, phosphoglycerate (PGA) (Breymeyer et al. 1996).

report further states that it is 'likely that the rate and duration of the warming of the 20th century is larger than any other time during the last 1,000 years. The 1990s are likely to have been the warmest decade of the millennium in the Northern Hemisphere, and 1998 is likely to have been the warmest year.' In addition, it is expected that increased concentrations of CO_2 and other greenhouse gases may lead to further significant temperature rises in the medium term (Houghton et al. 1994). In an examination of future climate scenarios for Ireland using high-resolution statistical downscaling techniques, Sweeney and Fealy (2001) suggest mean temperature increases of 2-3°C by the middle of the 21st century in both summer and winter in Ireland. Figure 1 illustrates these projections.

Apart from influencing other climatic factors such as rainfall, humidity and wind speed (Broadmeadow 2000), a warmer climate will have a direct impact on tree and forest growth. Virtually all chemical and biological processes in plants and soils speed up with warmer temperatures, and photosynthesis and respiration in trees are no exception (Saxe et al. 2001). The same authors conclude from a comprehensive literature review that, depending on N mineralization and availability, increased temperatures will lead to an increase in net primary production of forests in temperate and boreal (northern) regions, including Ireland.

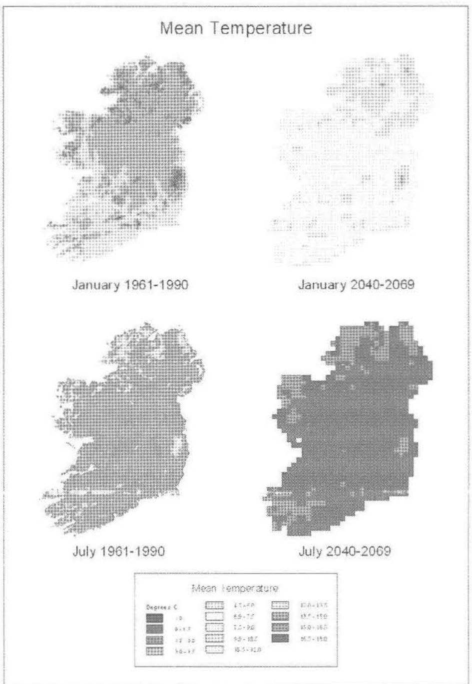

Figure 1. *Mean temperatures 1961-90 (baseline) and 2040-69 (downscaled) (Sweeney and Fealy 2001).*

The potential site productivity of Irish forests is assessed using an index called yield class, which is an estimate of the maximum mean annual increment of merchantable stem volume per hectare per annum (Edwards and Christie 1981). Yield class was found by Worrell (1987) to be closely correlated with both site temperature (estimated mean annual accumulated temperature above 5.6°C) and windiness. Analysis based on measurements from 142 sample plots found that these two climatic variables accounted for 78% of the variation in yield class. A multiple regression model developed by Worrell (op. cit.) would clearly indicate a rise in yield class with rising temperature, all other variables being equal.

Bud phenology (the periodicity of leafing, flowering and fruiting) is closely associated with temperature (Saxe et al. 1998). It is to be expected that, on lowland sites, an increase in average winter temperatures will result in later bud flushing of certain species including Sitka spruce, Norway spruce (*Picea abies*), ash (*Fraxinus excelsior*), beech (*Fagus sylvatica*) and sessile oak (*Quercus petraea*). This is because they require a certain number of chilling hours before bud flushing can take place in the spring (Cannell and Smith 1983, Thompson 1998). Later bud flushing in these species will result in a lower risk of damage from late spring frosts but may also mean a shorter growing season, potentially affecting production. However, Cannell and Smith (1983) argue that this effect would be lesser on upland sites where there would be more chilling hours through the winter than on lowland sites. In such situations, where sufficient chilling hours have occurred, earlier bud break may be expected and, hence, a longer growing season, as long as tender shoots are not damaged by late frost. For most species, the dominant trigger for shoot and bud growth cessation in autumn is night-length and not temperature (Saxe et al. 2001). Although shoot and bud growth may cease, it is possible that girth and volume growth will continue in warmer autumns.

Late spring frosts have caused considerable damage to early season growth of Irish forest crops, in particular Sitka spruce and ash planted on flat sites with low levels of air movement. Given that both winter and summer temperatures are expected to increase (Sweeney and Fealy 2001), it is reasonable to assume that frosts will be less frequent, particularly early autumn and late spring frosts. It is therefore likely that, because of their elevated locations, most Irish forest crops will commence growth earlier in the spring than at present. Also, species such as southern beech (*Nothofagus* spp.) and Monterey pine (*Pinus radiata*), previously thought of as unsuitable because of, among other factors, potential frost damage, may be reconsidered.

Increased storm frequency

In the projections of future climate change made by the IPCC (2001), increased frequency of strong wind and storm events are forecasted for the North-East Atlantic and Western Europe. The location of Irish forests, generally on exposed, windy sites with poor drainage renders them inherently vulnerable to wind damage. Irish forestry has recently suffered large losses to such events. In 1997, 1998 and 1999 Coillte, the Irish Forestry Board, reported about 0.5, 0.85 and 1.6 million m^3 respectively of roundwood being windthrown (Coillte 1997, 1998 and 1999). Britain suffers such events to a similar extent; it has been estimated by Quine et al. (1995) that, not counting extreme storm events, windthrow accounts for approximately 15% of the annual output of roundwood of Britain's forests. Up to 30% of the annual harvest in Ireland can comprise windthrown material (Forest Service 2000).

Ní Dhubháin (1998) suggests that, for existing forests planted on relatively exposed, ploughed sites and now reaching critical heights in relation to windthrow, the level of damage may increase. However, the same author suggests that younger forests, established on lower altitude, freer draining sites with improved cultivation and thinning techniques, should be more wind firm than those currently at risk.

Decreased rainfall

Figure 2 presents baseline (1961-1990) and a downscaled forecast (2040-2069) of summer and winter precipitation for Ireland (Sweeney and Fealy 2001). Potentially wetter winters for many parts of the west and midlands, and drier winters for the east and southeast are predicted. It is in the summer, however, that the most significant changes are forecasted with considerably less rainfall in all areas, with the exception of the northwest.

Soil moisture deficits are rarely encountered in plantation forestry in Ireland (Keane 1986). In general terms, reduced water availability, resulting from increases in potential evapo-transpiration and reductions in summer rainfall, may lead to loss of vigour on

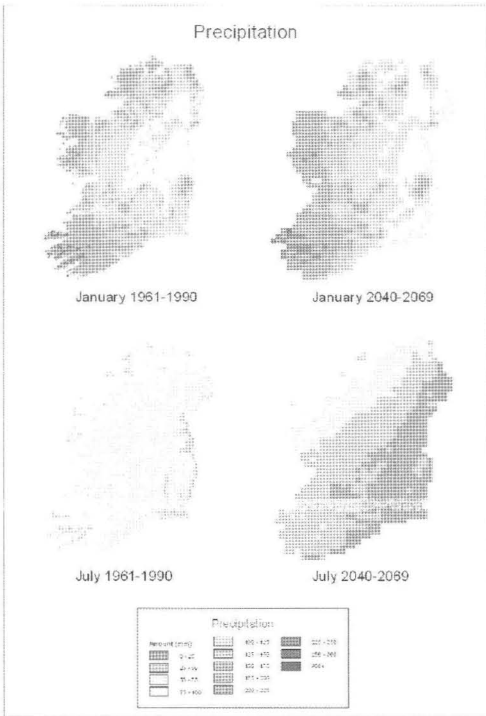

Figure 2. *Precipitation 1961-90 (baseline) and 2040-69 (downscaled) (Sweeney and Fealy 2001).*

some sites, particularly drier ones. However, this is very dependent on site type and species. A large proportion of commercial forests in Ireland are established on land considered marginal for agricultural use. Almost by definition, these sites are associated with high water holding capacities.

Periods of summer drought cause particular difficulties in the establishment of forests when roots have not yet fully developed and adjusted to their new environment. This has implications for current forest nursery practice and renewed research into the use of containerised stock or other methods of reducing planting shock may be worthwhile.

Potential secondary effects

Potential secondary effects are those indirect effects that may impact on tree or forest growth as a result of their primary effect on the forest ecosystem. A number of potential secondary effects are discussed in the context of the climate change projections and those potential primary effects discussed above.

Increased nutrient mineralisation

A key component of vegetation functioning is the maintenance of a nutritional balance. Given this, it is likely that responses to increased CO_2 levels will be limited by nutrient availability (Rastetter et al. 1992, Comins and McMurtrie 1993). Nonetheless, the responses of vegetation are also linked to the ability of vegetation to acclimatise to increased CO_2 concentration by making greater efforts to acquire limiting soil nutrients or by decreasing nutrient concentrations in biomass.

Thornley and Cannell (1996) suggest that, with regard to tree and forest growth, the crucial processes in climate change are those which affect the nitrogen (N) cycle. Forest productivity is strongly affected by N availability, since it is required in greater amounts than any other mineral nutrient (Saxe et al. 2001). In Ireland, N availability is most frequently affected by lack of drainage or the presence of competing vegetation.

Results from field and laboratory experiments show that elevated temperature will increase rates of organic matter decomposition and therefore nutrient availability (Saxe et al. 2001). However, overall soil warming effects on nutrient mineralisation may be no greater than the effects of continued nitrogen deposition, changes in vegetation, and natural and anthropogenic disturbance.

Forest pests and diseases

Elevated CO_2 is expected to alter foliar C levels, mineral nutrients and secondary metabolites. This is expected to have the effect of modifying insect and tree interactions (Saxe et al. 1998). In general terms, although each species has its own optimal temperature range, insect populations increase with increasing temperature. Insect populations will also exploit situations where trees are stressed because of, for example, drought, storm damage or flooding. There are a number of insects that either currently, or may potentially inflict damage on Irish forests because of climate change. Some of the more important ones are described below.

Green spruce aphid (*Elatobium abietinum*)
The green spruce aphid is present in Ireland and defoliates Sitka spruce, affecting all but the current year's growth. It rarely kills trees but can reduce productivity significantly, as has been experienced in a number of locations in Ireland over the last decade. Temperatures of below -7°C are required to kill off the aphid. Milder winters, particularly in drier areas, could result in large population increases and serious loss of growth on a regular basis.

Large pine weevil (*Hylobius abietis*)
The large pine weevil breeds in stumps and feeds on the vascular tissue of young trees during the establishment phase. It is one of the more serious insect pests in Irish forests, particularly on reforestation sites where breeding sites abound. A rise in average temperatures could result in greater pine weevil activity, particularly in combination with the effect of recent legislation banning the use of the pesticide lindane.

Great spruce bark beetle (*Dendroctonus micans*)
This species does not occur in Ireland but causes considerable economic loss in Norway spruce forests across Europe. Ireland, with large areas of spruce monoculture may well become vulnerable to this species, particularly in areas such as the east and southeast, where drought-induced stress may become significant and predispose the trees to attack.

The potential effects of climate change on a number of diseases that currently or could potentially afflict Irish forests are outlined below.

Fomes (*Heterobasidion annosum*)
Fomes, a root and butt rot, is currently the most economically damaging disease affecting Irish forestry. It spreads in a number of ways, such as through root contact and mycelial growth, but most importantly through the infection of freshly cut stumps by spores. The optimum temperature for its growth is 22.5°C (Rishbeth 1951). Fructifications are relatively resistant to both drought and moderate frost. This suggests that fomes may become more of a threat in a warmer and drier climate.

Phytophthora disease of alder
This fungus invades the stem and roots of alder and spreads to the connecting tissue of the bark causing die-back and death. It has only recently been identified as present in Ireland; it is possible that its recent expansion is an indication of environmental change.

Honey fungus (*Armillaria mellea*)
Honey fungus is one of the most widespread of all root and butt rot disease fungi. Its mycelia and rhizomorphs grow optimally at between 20 and 25°C, while fruit body formation is optimal at 25°C. Drought conditions have often been considered to render trees more liable to infection (Phillips and Burdekin 1982). It would therefore seem reasonable to suggest that climate change as forecasted will provide more favourable conditions for its spread.

Injurious mammals

Broadmeadow (2000) suggests that both deer and grey squirrel populations may respond positively to warmer winters in Britain. The population and range of both is increasing in Ireland. Environmental change resulting from higher temperatures and other factors could result in them posing an even more serious threat to economic forestry.

Forest fire

Forest fire in Ireland is relatively infrequent compared with other countries. About 450 ha are lost each year, mainly in the period from February to September, with the vast majority of outbreaks occurring in March, April and May. Rainfall, humidity, wind and temperature influence the flammability of competing vegetation, the tree crop and, on peat sites, the soil itself.

Warmer and drier conditions, particularly in the spring and early summer, can only serve to increase the risk of fire in Irish forestry. However, Keane (1993) points out, that as most forest fires in Ireland start outside the forest, it is more important to assess how climate change will affect other vegetation types before predicting whether forests themselves will be impacted.

Interaction of climate factors

In the previous sections the potential impact of changes in individual climate factors has been reviewed. However, it is clearly the interaction of different factors and their potential combined effects on forest growth that is of real interest and concern to forest owners and managers. Breymeyer et al. (1996) warn that failure to take account of the interaction of climate factors can lead to errors in the prediction of their overall potential impact.

There are a number of models which attempt to project the potential impact of climate change on forest ecosystems. As discussed earlier, this is a highly complex task, and results are generally as much a function of model design as they are of model inputs. Despite this, huge progress has been made in modelling the potential impact of climate change on forests.

Thornley and Cannell's (1996) work on temperate forest responses to CO_2, temperature and nitrogen changes is perhaps the most interesting from an Irish forestry perspective. This work involved the simulation of responses in a managed conifer plantation in upland Britain, a scenario typical of Irish forestry. It found that rising temperature, along with rising CO_2, may either increase or decrease forest productivity on such sites, depending on the rate of supply of N and changes in water stress. The particular model used analysed the potential impacts based on projected increases from 350 to 550 μmol mol^{-1} CO_2 and 7.5 to 9.5°C (mean annual temperature)[3]. Goodale et al. (1998) drew similar conclusions, stating, 'Site specific conditions and management practices result in a range of forest productivity that is much greater than any likely to be induced by climate change or CO_2 enrichment'. Further evidence to suggest that soil fertility limits carbon sequestration by forest ecosystems in a CO_2 enriched atmosphere

[3] The ITE Edinburgh Forest Model (Thornley 1991).

is provided by Oren et al. (2001). They point out that forests are usually relegated to sites of moderate fertility where tree growth is often limited by nutrient supply, in particular nitrogen.

Joyce and Nungesser (2000) suggest that forest productivity may increase under elevated CO_2, but that the local conditions of both moisture stress and nutrient availability will strongly temper any response. Thornley and Cannell (1996) suggest that, because water use efficiency is expected to improve in an elevated CO_2 environment, temperate forests may be protected from the predicted water stress resulting from increased temperatures.

Many of Ireland's commercial forests are located on poor quality land drained specifically for the purpose of afforestation. Without the addition of P and/or N fertiliser, many of these forests might never have successfully established and grown. On such sites it is therefore possible that limitations in the supply of N and P will temper any potential for increased biomass production due to CO_2 fertilization or increased rates of photosynthesis. Further application of N and/or P fertiliser is possible but this has economic implications. However, much of the more recent planting has been on better sites where nutrient availability should not be limiting. These forests, along with older forests established on good sites, may have increased productivity in a CO_2 enriched and warmer climate, as long as water availability does not become limiting during the growing season.

Breymeyer et al. (1996), while acknowledging that nutrient limitation may negate the CO_2 fertilisation effect, maintain that C_3 plants will actually behave more efficiently in their use of nutrients in an elevated CO_2 environment. This agrees with the conclusions of Thornley and Cannell (1996) who state that, as a result of increased CO_2 levels, N acquisition (where available) and N-use efficiency will both increase, giving rise to increased ecosystem productivity and carbon storage. Cannell et al. (1998) tested this theory by using both the ITE Edinburgh Forest Model and the Hybrid Model (Friend et al. 1997). Both of these models associated historical increases in Net Primary Productivity (NPP) and yield class with increased CO_2 levels, temperature and N deposition. Significantly, however, they also both predict that the current rate of increase in productivity will continue until the end of the 21st century, with an increase in average yield class of about 5 m^3 ha^{-1} $year^{-1}$ and an increase in NPP of between 24 and 34% between 1990 and 2050.

Although increased CO_2 levels in the atmosphere are expected to increase water-use efficiency within trees, it is not necessarily correct to conclude that this will result in greater drought tolerance (Tschaplinski et al. 1995, quoted in Saxe et al. 1998). The increased water-use efficiency may be offset by increased leaf production (Broadmeadow 2000) and increased leaf area associated with increased N availability (Thornley and Cannell 1996), both resulting from elevated CO_2.

Forecasted increases in wind speed and the frequency of severe gales suggest that Irish forestry will continue to suffer from wind damage, and to a greater extent than in the past. However, as pointed out by Ní Dhubháin (1998), the increased afforestation of lower lying sheltered farm sites may mean that a higher percentage of Irish forests will be less vulnerable in the future. Shallow rooting and poor anchoring of trees as a result of impeded drainage and root alignment along plough ribbons are often the cause of windthrow in Irish forest crops. In a decreased rainfall scenario which may result in a lowering of the water table on some sites, it is conceivable that windthrow risk will be reduced. However, wind damage is not limited to windthrow. Wind snap can result in greater economic damage than windthrow as it renders the stem unusable for structural purposes because of splitting and shattering, whereas sawlog is commonly salvaged from wind thrown crops. The risk of wind snap would appear to be greater in the future, assuming improved root anchorage and increased leaf area and thus canopy resistance to wind.

It is generally accepted that trees and forests exhibiting vigorous growth are less susceptible and quicker to recover from damage by pests and diseases. It is therefore difficult to predict what might happen to Irish forests in a situation where growth is stimulated by CO_2 fertilisation and increased temperature, while at the sane time climatic conditions favour a dramatic rise in the populations of damaging pests and diseases.

Tree species have different optimal conditions for flowering and the production of seed. Generally these are weather and climate related. For both broadleaves conifers, conditions at the time of pollination determine the number of normally developed seeds that are formed. Dry, sunny and windy weather at this time will result in greater numbers of full seeds than dull, wet and still weather (Gordon 1992).

Forest management and policy implications of climate change

A mild and moist maritime climate is the single overriding factor that gives Ireland its competitive advantage in forest productivity over other European countries. For this reason, any implications of climate change are of great importance to the Irish forestry sector. This section discusses some potential implications for foresters and policy makers.

Species and provenance selection

The Irish forest industry is heavily reliant on exotic coniferous species. These have been selected by foresters as suitable for growth in the prevailing Irish climate and on existing Irish site types. Coniferous crops are generally grown over rotations of between 35 and 60 years. Unlike agriculture, there is no opportunity, without undertaking a premature felling, to replace species with one that is more suitable until the prescribed rotation is complete. Therefore, foresters planting forests now must make species selection decisions in the context of potential climate change. A decision taken today means a commitment of 35 years or more to a particular species and provenance. From the point of view of matching species to climate and site, it is reasonable to expect that a gradual climate change, although affecting growth in ways discussed earlier, can probably be accommodated, through suitable species and/or provenance selection, without it resulting in serious losses. However, a climate ‘flip’, such as suggested by Fleming (1998), may have more serious consequences.

Sitka spruce has a natural distribution that follows the wet coastal region of north-west America. It has a high moisture requirement; MacDonald (1952) reports that, in Britain, it is rarely seen at its best in areas of less than 1000 mm $year^{-1}$. This suggests that, apart from in mountainous areas, it may become less favourable a species along the east coast and in the south-east of Ireland, particularly if defoliating green spruce aphid populations take advantage of crops exhibiting water stress. However, apart from the frost tenderness of new growth, the growth of Sitka spruce appears to be relatively independent of temperature variations (MacDonald op. cit.) There is therefore no apparent reason, apart from in the areas discussed above, to suggest that this species will not continue to be the mainstay of commercial forestry in Ireland.

Current Irish forest policy is to diversify the range of coniferous species planted. The main alternatives to Sitka spruce are Norway spruce, Douglas fir and Japanese larch. Norway spruce is a species associated with a continental climate and is thus more tolerant than Sitka spruce of drier summers on drier sites. Douglas fir has an extensive natural range from coastal British Columbia in Canada to coastal California, inland as far as Colorado, with pockets extending into Arizona and Mexico. Coastal provenances from Washington are currently used in Irish forestry but there is evidently good potential for other provenances of this species to be used if climate change occurs as forecasted. However, Douglas fir is intolerant of flooding and this may limit its use if wetter winters result in flooded forest sites. In contrast, Japanese larch has a very small natural range and a consequently limited provenance range. It grows extremely vigorously in its early years, often resulting in poor stem form. Even more vigorous growth caused by warmer conditions and CO_2 fertilisation may exacerbate this problem and reduce log value. Western red cedar is a valuable timber species but is little used in Irish forestry, with only 40 ha of new forest being established each year (Forest Service 2001). It thrives under wet and mild conditions and on heavy soils with a high water-holding capacity. The inland part of its natural range is characterised by relatively dry summers. This species should be investigated further as one with serious potential for use in a climate change scenario. Keane (1993) suggests some other species that might be considered for future use, such as eucalyptus, southern beech (*Nothofagus* spp) and Monterey pine.

Thompson (1998) points out that genetic traits associated with adaptability to local conditions exist not just at species level, but also at provenance, family and individual level. Saxe et al. (1998), in a review of current knowledge on tree and forest functioning in an enriched CO_2 atmosphere, reference various studies that have shown different responses to CO_2 enrichment between species, hybrids of the same species and even between different families within species. Bazzaz et al. (1995) suggest that future CO_2 levels would lead to increased intensity of natural selection. There is considerable genetic variation within coniferous species used in Ireland, and seed sources, although of a specific provenance, are essentially wild and unlike agricultural crops, with little selection for optimisation of traits for Irish climatic, site and market conditions. This is supported by COFORD (1994) which indicates that although there are tree breeding programmes in place for most species, there is little genetically improved seed used in Irish forestry. It follows that, in a climate change scenario, there is good potential for continued use of existing species, with increased selection for traits that will accommodate the predicted environmental changes.

Forest site location

In the past, forestry has generally been located on land that was not economically viable in agricultural use. This is still the case, although to a lesser extent, particularly with the availability of grants and premiums for afforestation. The potential impact of climate change on Irish agriculture is therefore of critical importance to Irish forestry, as it may have a bearing on where and how afforestation will occur in the future. However, it is likely that it will continue mostly on wet land that is marginal for agriculture. There is nothing to suggest that these sites will ever become unsuitable for forestry. However, the importance of matching species to site has never been more important and it should no longer be assumed that the site will not alter significantly during the course of the rotation.

Forest establishment and management

Current forest establishment practice in Ireland involves cultivation and drainage, and protection using fencing and vegetation control. Other operations such as fertilising and the creation and maintenance of firebreaks also take place to a limited extent. Tree planting is carried out in the dormant winter season, although the use of cold-stored plants means that the planting season can be extended into late spring. In a potentially milder climate, the timing of a number of these operations may become more critical. On some sites, the use of machinery in cultivation and drainage is currently restricted by wet winter conditions. In a scenario where winters become generally wetter, it may become necessary to complete all drainage and cultivation work in the summer or autumn prior to planting rather than in conjunction with planting, as is currently practised. Competing vegetation will probably benefit from an extended growing season and increased growth rates; its control may therefore require earlier and more frequent interventions. Similarly, depending on species, the dormancy period may be affected, with a resulting effect on optimal planting dates. Post-planting care may also become more critical, particularly in areas experiencing warmer, drier summers which are often the cause of tree mortality in newly planted areas. The use of container-grown transplants, used in some countries to extend the growing season and reduce planting shock, may therefore become more favoured. Fire management is likely to become increasingly relevant with warmer and drier summers; extra resources may be required in order to militate against the risk of economic loss due to fire.

Harvesting and transport

The principal forms of forest harvesting undertaken in Irish forests are thinning and clearfelling. These are carried out using heavy machinery which may, as part of a harvesting plan, be seasonally restricted as a result of wet weather or waterlogged sites. For this reason, certain sites are considered as 'summer sites', as they are best harvested during the drier summer months. If Ireland is to experience wetter winters and drier summers as a result of climate change, there may be increased pressure to harvest on a greater number of sites in summer. This may cause logistic problems for the harvesting sector to supply sufficient quantities of roundwood during the winter.

Silvicultural systems

Conventional practice within the Irish forest industry is to operate a silvicultural system using even-aged crops of generally not more than two species grown over an optimal financial rotation, followed by clearfelling and reforestation. There are many alternative silvicultural systems to clearfelling, and the prospect of climate change provides an appropriate opportunity to consider their relative merits vis-à-vis their potential ability to cope with a changing climate.

The clearfell system offers the forester the opportunity to begin with a new species and management regime that match the prevailing site and climatic conditions. Alternative systems do not afford this opportunity to the same extent. However, the bare establishment site is a relatively harsh environment for young trees, exposed to wind, drought, attack from pests and vigorous competing vegetation. Group and continuous cover silvicultural systems offer the newly planted or naturally regenerated tree a more protected environment in which to establish. These alternative silvicultural systems also appear to be less susceptible to wind damage, leaving fewer exposed edges than clearfelling and providing a diverse stand height structure that, in addition to providing mutual crown support, effectively filters wind rather than behaving as a resistive barrier. From a purely economic viewpoint, the economies of scale associated with clearfelling cannot be matched by alternative silvicultural systems. However, it is still perhaps too soon to economically assess the sustainability of production from clearfelling and alternative systems.

Forest health and protection

Predicted downscaled climate change scenarios for Ireland (Sweeney and Fealy 2001) show warmer and drier summers over the period 2040-2069, particularly in the southeast and east of the country. Forests in these areas are likely to suffer from increased frequency and severity of insect and disease damage as a result of drought induced stress. These warmer, drier conditions will also make Irish forests more vulnerable to the introduction of pests such as the great spruce bark beetle. Current policies on preventing entry will require regular review. Most timber shipped to Ireland from Europe arrives at ports in the east and southeast, which adds to the risk of pest introduction.

Measures currently in place to limit the spread of fomes include a legal requirement to treat all freshly cut stumps with a urea solution which renders them inhospitable to colonisation. It is unlikely that any further measures would be cost-effective in controlling the spread of this or other diseases.

Forecasted climate change scenarios would suggest a more favourable habitat for already damaging mammals such as deer and grey squirrel. Regional management plans will be necessary for the control of these species, as they cannot be effectively managed on an individual site basis.

Carbon sequestration

The ability of forests to sequester atmospheric CO_2 is well documented. The ability of Irish forests to function as carbon sinks in a changed climate remains uncertain. While the combined effects of stimulated photosynthesis and reduced respiration result in increased rates of carbon sequestration, there is evidence that soil warming may increase C losses from soil by accelerating microbial respiration and dissolved organic carbon leaching (Mac Donald et al. 1999). In a study of the impacts of terrestrial ecosystem warming in tundra, grassland and forest, Rustad et al. (2001) found that soil warming increased soil respiration, nitrogen mineralisation and plant productivity. In contrast to these findings, Liski et al. (1999) found that the amount of carbon in Finnish soils of both high and low productivity forest types actually increased with temperature. Given the scientific uncertainty which exists, it is clear that in order to understand the possible effects of climate change on the carbon cycle in Irish forests, studies of the importance of specific factors such as moisture, temperature, soil type, land use history, etc. at different spatial and temporal scales will be required. Any future changes in the carbon balance of our forests will have implications for national strategies to reduce greenhouse gas emissions.

The use of woody biomass as a renewable energy resource may also become an important tool in the Government's Climate Change Strategy. The use of woody biomass is already an important component of the renewable energy sectors of other European countries. It is likely that the Irish forestry sector will be charged with the responsibility of creating and managing such a resource in the future.

Research and development

It is evident that climate change as forecasted both internationally by the IPCC and nationally through research such as that of Sweeney and Fealy (2001) will impact on Irish forestry.

Research areas identified by COFORD (1994) as being of strategic importance such as forest genetics and tree breeding, forest health and vitality, silviculture, nursery research and development, are all potentially affected by climate change. It is important that all such research acknowledges and accounts for potential changes in the Irish climate. A number of specific areas requiring further research have been identified and are summarised as follows:

- Recent advances have been made with the introduction of dynamic yield models. These should be regarded as a stepping stone to more holistic forest ecosystem or process-based models. Through simulating ecosystem processes, these should ultimately predict the development of the ecosystem over time and in response to changing environmental conditions. The output of models will encompass not only forest production, but also the wider issue of sustainability of the forest ecosystem.
- Long-term research is required into the potential impact of climate change on organic matter turnover and N mineralisation.
- There is a need to continue to assess different provenances and species in long-term research trials. It is recommended that particular attention be paid to alternative provenances of Douglas fir and western red cedar.
- The national tree breeding programme should be reassessed in the light of current knowledge on potential climate change and with a view to the selection of traits that will accommodate and capitalise on these changes.
- The potential for the production and transplanting of containerised nursery stock

should be reassessed.

- Climate change scenarios should be included in the Forest Inventory and Planning System operated by the Forest Service in the Department Agriculture and Food.

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Preliminary estimates of biomass carbon stock changes in managed forests in the Republic of Ireland over the period 1990-2000

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Abstract

National reporting requirements to the United Nations Framework Convention on Climate Change on carbon sequestration in forests and harvest include estimates of changes in biomass stock in the forest estate over time. Incomplete inventory records have meant that yearly records of total forest increment were not available. A time series was constructed for Irish forests for the period 1990-2000 using forest area categories defined in the forest inventory and planning system of the Forest Service. These data were supplemented by planting and felling data. Carbon stock changes are presented for the year 2000 and show a net increase of 160,000 t of carbon after harvest. Calculations are carried out in a flexible spreadsheet model which can be updated as new data on biomass expansion factor comes to hand.

Key words: Biomass, carbon stocks, UNFCCC, sink

Introduction

Forest vegetation is a major component of the global carbon (C) cycle and is estimated to store at least 350 Pg C (Dixon et al. 1994). This is subject to increase or decrease as a result of factors such as harvest, re-growth, conversion to other land uses, with resulting changes in C fluxes to the atmosphere. There is an ever-increasing need to improve the accuracy of estimates of C storage in forest biomass so that its role in the global C cycle can be characterised and understood. The advent of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol have also added impetus to the need for such information.

Forest inventory data, in combination with yield models are is the most practical means for estimating biomass C stocks and changes. Yield models have the advantage that they can be used for different age classes and forest types. However, they should reflect potential changes in growth as a result of changing climatic and environmental conditions and may therefore need updating.

Carbon removals can be estimated using harvest statistics. However, forest inventory is usually only concerned with the merchantable stemwood volume. Therefore, estimates of biomass C stock need to take into account the non-stemwood biomass components such as braches, foliage, stumps and roots. This is commonly done using biomass

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expansion factors (BEFs), which express the ratio of merchantable biomass to total biomass.

Carbon accounting methods for Irish plantation forests are at an early stage of development. The first published assessment of biomass C stocks in Irish forests was by Kilbride et al. (1999). Since then the policy framework has continued to develop with the publication of the National Climate Change Strategy (Department of the Environment and Local Government 2000) and Ireland's ratification of the Kyoto Protocol in 2002.

In 2000, following a request from the UNFCCC for additional information on net carbon uptake in forests in the Republic of Ireland during 1998, COFORD (the National Council for Forest Research and Development) commissioned a study to estimate carbon increment and carbon removed in harvesting during that year (Gallagher 2000, COFORD 2001). This was followed by a request from the Forestry Climate Change Team of the Department of Communications, Marine and Natural Resources to develop an annual time series of C stocks in Irish forests over the period 1990 to 2000 which would form a baseline for forest C accounting in the Republic. This paper reports on the approaches used to determine these statistics.

Materials and methods

Data sources

Data were assembled from a number of sources. Forest inventories have been carried out in state owned forests since the 1950s (O'Flanagan 1973). In 1989 the Irish state involvement in forestry underwent a radical change resulting in the formation of two organisations: the Forest Service, the statutory authority responsible for forestry administration and Coillte, the Irish Forestry Board a state sponsored company owning and managing the public forests. While the last inventory of private forests was carried out under the Forest Service as far back as 1973 (Purcell 1979), Coillte's inventory covers all their forest areas and is updated regularly. Coillte also records information on its thinning and felling harvests.

Since the late 1980s, privately owned woodland has become a very significant part of the national estate. It currently accounts for 39% of the total forest area (Hendrick et al. 2002). A full survey of all state and private forests was completed in 1996 under the Forest Service's Forest Planning and Inventory System – FIPS (Fogarty et al. 1999). It provides information on areas by species development category for all forests identified by remote sensing. The second phase of FIPS, a sample based inventory of standing volume, stocking and other variables commenced in 2003 with a pilot study in Co Wexford.

Private and state planting can be tracked through Forest Service recent internal reports (Forest Service 2000) and Ministers' reports on forestry (Ministers' Reports 1980-1988).

The United Kingdom (UK) Forestry Commission yield models (Hamilton et al. 1971) are reasonably reliable as a source of production data for plantation species grown in Ireland. Irish models are available for a limited number of species such as coastal lodgepole pine (*Pinus contorta* var *latifolia*) (Forest and Wildlife Service 1975), which still comprises a significant part of the national forest estate. Irish models have recently been constructed for Sitka spruce (Coillte 2003) and other species but they have not been fully validated yet and have, as yet, not been used for estimation of carbon stocks and increment.

Conversion factors relating wood volume to biomass and thence to carbon have been developed by the UK Forestry Commission (Hamilton 1975). These are in the range used by the Intergovernmental Panel on Climate Change (IPCC) (Houghton et al. 1996) and have been used in recent reports and studies on carbon storage in Ireland (Kilbride et al. 1999). In this paper the Forestry Commission factors for basic (dry) density are used in combination with IPCC default values for carbon content. BEFs used were those estimated by Black et al. (2004), which take into account age related changes in biomass distribution in Irish forests. These BEFs are higher than those used in previous national reporting to the UNFCCC (McGettigan and Duffy 2003) and, as they are based on sampled trees are considered to reflect better Irish forest conditions.

Carbon content of the national forest estate

The main problem in estimating carbon stocks and increment was to accurately model the development of the national forest estate given the relative paucity of quantitative data. Two approaches were considered:

1. To base the time 1990-200 time series mainly on Coillte inventory information and supplement this with largely speculative information for the private sector, or
2. To use FIPS data for the total forest estate, which are area based but lack wood volume and increment data for the different strata.

The second approach was used, supplemented with yield data from Coillte forests and using Irish and UK yield models to determine wood production and thence C stocks and stock changes in Irish forests.

Given that the FIPS database represents the national forest estate for year 1995 only, it was necessary to arrive at assumptions as to how it developed between 1990 and 2000. Another problem was that FIPS updates since 1995 include non-surveyed planting-grant-data in the different strata, so the basis of 1995 data and those of later years was different.

A time series of forest strata by age and area was constructed using the FIPS base year of 1995. This comprises recorded and interpreted information for identified forests. A considerable area of very young, cleared or unclassified (uninterpreted) forest is included in the 1995 data, and estimated in the time series as a separate category for information purposed. The latter had little impact on the contribution to carbon storage or stock changes over the period.

The three broad categories identified by FIPS are:

1. Cleared/unclassified (including young plantings),
2. Young crops and
3. Mature crops.

The latter two categories are further broken down into species categories to provide the individual strata (Table 1). Over time there is a movement from cleared areas to young to mature crops and back to cleared, as stands are planted or reforested, grow to maturity and are felled (Appendix 1). This is the pattern assumed in the model. How this movement takes place will be determined by the rates of afforestation, clearfelling and reforestation taking place prior to and during the series.

Table 1. *FIPS categories by area for 1995 and their relationship to the strata used to report to the UNFCCC.*

FIPS stratum	*Abbreviation*	*Area 1995 ha*	*Reporting stratum*
Conifer spruce young	CYS	92,407	*Picea*
Conifer larch young	CYL	1,031	Other coniferous
Conifer pine young	CYP	29,083	*Pinus*
Conifer pine/spruce young	YPS	10,575	*Picea* 50%, *Pinus* 50%
Conifer other young	CYO	7,101	Other coniferous
Broadleaf oak young	BYK	218	*Quercus*
Broadleaf beech young	BYB	161	*Fagus*
Broadleaf other young	BYO	6,055	Other broadleaf
Mixed young	MXY	4,480	Mixed broadleaf conifer forest
Conifer spruce mature	CMS	93,004	*Picea*
Conifer larch mature	CML	3,502	Other coniferous
Conifer pine mature	CMP	32,608	*Pinus*
Conifer pine/spruce mature	MPS	27,369	*Picea* 50%, *Pinus* 50%
Conifer other mature	CMO	9,453	Other coniferous
Broadleaf oak mature	BMK	5,600	*Quercus*
Broadleaf beech mature	BMB	3,072	*Fagus*
Broadleaf other mature	BMO	43,233	Other broadleaf
Mixed mature	MXM	24,479	Mixed broadleaf conifer forest
Other	O	1,900	Other forest
TOTAL FIPS COVER		395,331	
Cleared/unclassified [1]	CUC	180,777	Unclassified young forest plantations
TOTAL AREA IDENTIFIED BY FOREST SERVICE		576,108	

[1] This includes the FIPS cleared category and the balance of area to make up the Forest Service total area for 1995.

Carbon removals through harvesting

Coillte records (Coillte 2001) represent the main source of data for wood harvesting. These data are compiled through the company's timber sales reporting system and are available for the period since 1991. Detailed information is sparse for the private sector. In this instance recourse was made to a forecast of production for all forests in the Republic of Ireland (Gallagher and O'Carroll 2000) to estimate the private sector harvest.

Assumptions made in relation to the FIPS categories

Age

Cleared areas were assumed to include crops less than 7 years old. Young crops were assumed to include crops from 7 to 25 years old. Mature crops were assumed to include crops from 25 years old to year of final harvest.

Species categories

FIPS categories (Table 1) were regrouped into categories suitable for reporting in the format of the Table 5a categories in Houghton et al. (1996): *Quercus*, *Fagus*, Other broadleaves, *Pinus*, *Picea* and Other conifer (*Abies* is not classified and was therefore included with other conifers).

Yield prediction

The Coillte average weighted yield class (wood production model) was applied to all state and private sector forests for each of the FIPS species categories (Table 2). Young broadleaves were given representative yield class estimates based on expert knowledge.

Area

The FIPS 1995 areas were accepted as the baseline area for all strata except that classified as cleared (while accepting that the latter case would have included some very young grant-aided forests not identified by remote sensing as having forest cover). In this instance, the Forest Service figure, compiled from national statistics for the total

Table 2. *Yield classes assumed for the FIPS strata.*

FIPS stratum	*Yield class* $m^3ha^{-1}yr^{-1}$
Spruce	16
Pine	10
Larch	8
Other conifers	14
Mature oak and beech	4
Other mature broadleaves	6
Young oak and beech	6
Other young broadleaves	8

forest area of a given year that year, minus the total of all the FIPS categories, plus the FIPS cleared category, was used to estimate the cleared/unclassified area (see footnote 4). Using this approach for the years from 1995 to 2000 allowed the forest area to grow to the total forest area estimated by the Forest Service, from all sources, for the year 2000. A fuller description of this methodology is outlined in Appendix 1.

Crop volume production

Volume was determined from the UK and Irish yield models (Hamilton et al. 1971, Forest and Wildlife Service 1975). Main crop volume after thinning was used in conifers. The ages assumed for young and mature conifers were 15 and 35 years respectively.

Young broadleaved crops were allocated a nominal standing volume of 10 m^3 ha^{-1}. In the case of mature broadleaved forests volume was determined from the total wood plus firewood volume recorded in forest estates during the last inventory of private woodlands (Purcell 1979), divided by area.

Mixed mature forest volume was based on the average of the mature other conifers and broadleaves strata.

Volumes were first allocated to the FIPS strata and were then redistributed by species x area categories to be used for reporting to the UNFCCC and converted to carbon equivalents (Table 3). Standing volume was reduced by 15% to allow for roads and rides. Average standing volumes for the UNFCCC categories changed each year (Appendix 2) as a result of area weighting when converting from the FIPS categories.

Change in forest areas over time

It was assumed that forest areas changed over time in the following manner:

1. Afforested and reforested[2] areas, as determined from Forest Service planting records and Coillte clearfell data, currently described as cleared, moved into the young category when they reached 7 years of age. The impact of deforestation was minimal in this period.
2. An equal percentage of young crops moved each year into the mature category. This percentage is related to the time span between the minimum and maximum ages defined for young crops. In this case (minimum age 7 years) the turnover is 18 years equivalent to 5.6% per year.
3. Clearfelled areas (assumed to equate to, and occur the year prior to, reforestation) together with an estimated 200 ha^{-1} yr^{-1} for the private sector, moved each year from the mature to the cleared category.
4. An exception was made for mature oak and beech where, because of increasing constraints on clearfelling of broadleaves, no clearfelling was assumed over the period (1990 – 2000).
5. Clearfelling was allocated to strata on the basis of their FIPS mature category distribution.

[2] Reforestation is regeneration after felling, not planting of former forest land that has been converted to agriculture or another land use, which latter is the Marrakesh Accords definition.

Table 3. *Standing volume and conversion factors used for the FIPS strata.*

FIPS statum	*Standing volume*	*Reduced Volume*	*Biomass expansion factor (BEF)*	*Dry (basic) density*	*Carbon content*	*Carbon*
	$m^3\ ha^{-1}$			$t\ m^{-3}$		$t\ ha^{-1}$
(a)	*(b)*	*(c)= b x 0.85*	*(d)*	*(e)*	*(f)*	*(g) =c x d x e x f*
CYS	57	48.5	2.0	0.350	0.5	16.975
CYL	46	39.1	2.0	0.440	0.5	17.204
CYP	40	34.0	2.0	0.400	0.5	13.600
YPS	48	40.7	2.0	0.375	0.5	15.263
CYO	52	44.2	2.0	0.400	0.5	17.680
BYK	10	8.5	2.0	0.550	0.5	4.675
BYB	10	8.5	2.0	0.550	0.5	4.675
BYO	10	8.5	2.0	0.550	0.5	4.675
MXY	30	25.5	2.0	0.480	0.5	12.240
CMS	256	217.6	1.4	0.350	0.5	53.312
CML	206	175.1	1.4	0.440	0.5	53.931
CMP	190	161.5	1.4	0.400	0.5	45.220
MPS	221	187.7	1.4	0.375	0.5	49.271
CMO	233	198	1.4	0.400	0.5	55.440
BMK	255	216.7	1.4	0.550	0.5	83.430
BMB	256	217.6	1.4	0.550	0.5	83.776
BMO	160	136	1.4	0.550	0.5	52.360
MXM	175	148.8	1.4	0.480	0.5	49.997
O	150	127.5	1.4	0.550	0.5	49.088

To estimate the rate of change prior to 1995, the process was worked in reverse (see Appendix 1).

Determining carbon stocks and harvest

Total carbon content was determined as:

basic density x carbon content (for the different species based on Hamilton 1975 and Houghton et al. 1966) x biomass expansion factor (BEF) (Black et al. 2004).

This calculation was used to convert the reduced timber volume to carbon (Table 3). Carbon storage in the FIPS categories was then converted to the categories to be used for reporting to the UNFCCC (Table 4 and Appendix 2).

In the guidelines on methods for reporting changes in carbon in forest biomass stocks (Houghton et al. 1996 Table 5a), increment values are used to determine annual increments in carbon stocks and from these the harvest is subtracted to find the net changes in carbon stocks. (This is analogous to Article 3.4 of the Kyoto Protocol, which can be paraphrased as: human induced net changes in carbon stocks). Here we modified the table to use reduced actual standing volumes (less thinning) on a net area basis to estimate standing volume. Increment was then calculated by subtracting from the carbon stock in year n the carbon stock in year n-1. This is the increment in stock less the harvest, as the thinning volumes have already been removed from the data used, and the areas are net of clearfelled volumes.

In order to compare stock changes derived from the model with those presented in the common reporting format the annual wood harvest volume which was estimated independently from Coillte and private sources was converted to carbon using the same conversion factors. The harvested volume includes firewood, which is estimated to be in the region of 30,000 m^3 yr^{-1} (Appendix 2). (Carbon dioxide emissions from the use of firewood are estimated but not reported under the general reporting format as the process is assumed to be carbon-neutral (Duffy 2003)).

Results

Carbon stocks in the national forest increased by an estimated 2.3 Mega tonnes[3] (15.9 to 18.2 M t C) over the period 1990 to 2000 (Table 4). When carbon removed in harvest is added to the net annual increase in forests after thinning, the gross carbon stock change increased from 0.73 M t C to 1.2 M t C over the period. This was despite an annual harvest which increased from c. 0.51 to 0.91 M t C over the same period (Figure 1).

The average annual net increase in carbon stocks over the eleven years was 0.23 M t C. This had increased to 0.28 M t C by 1998, decreasing to 0.21 M t C in 1999 and recovering to 0.26 M t C in 2000. Overall the rise has been uneven, probably reflecting changing patterns in planting and increases in clearfelling. The impact of lower rates of new planting in the mid 1980s on the movement of cleared/unclassified areas to young

Table 4. *Carbon stocks, harvest and net changes in stocks over the period 1991-2000.*

Year	*Standing carbon stock*	*Carbon stock change*	*Harvest*	*Net carbonstock change*	*Harvest as a percentage of annual increment*
		Mt C			*%*
1990	15.887	0.725	0.509	0.216	70
1991	16.114	0.764	0.537	0.227	70
1992	16.299	0.818	0.632	0.186	77
1993	16.508	0.847	0.638	0.209	75
1994	16.708	0.894	0.694	0.200	78
1995	16.928	0.943	0.723	0.219	77
1996	17.146	0.967	0.748	0.219	77
1997	17.397	0.956	0.705	0.251	74
1998	17.679	1.083	0.801	0.282	74
1999	17.885	1.049	0.843	0.206	80
2000	18.145	1.174	0.913	0.260	78

[3] One Mega tonne is one million tonnes.

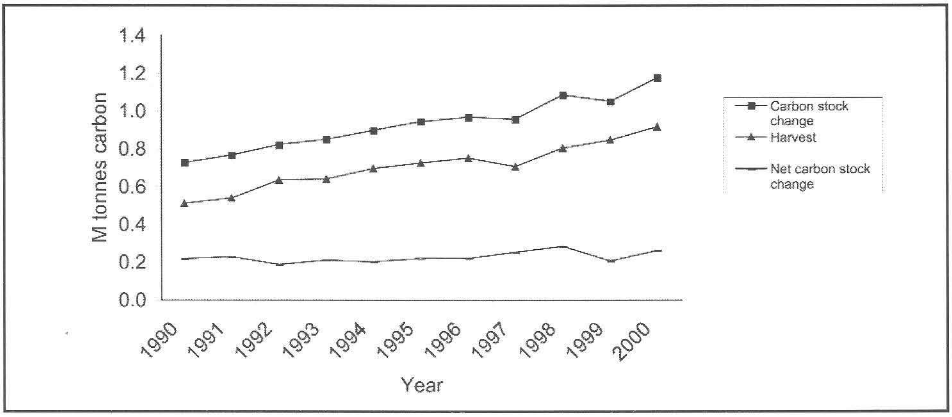

Figure 1. *Comparison between wood harvest and net carbon stock change in Irish forests over the decade 1991-2000.*

crops, and the movement of mature crops to cleared, has probably resulted in this fluctuating pattern, although the carbon stock of the total forest estate continues to increase as a result of the afforestation programme. The very high rates of planting in the mid 1990s had not made a significant impact on carbon stocks or increment by the year 2000. These areas would only start to move from cleared/unclassified to young crops during this period. Overall it is estimated (Table 4 that between 70% and 80% of the carbon stock increment was removed in harvesting.

It is of interest to note that the difference between gross increment and cut for the national estate was 0.28 M t C or 74% compared with 0.13 M t C or 87% reported by Coillte for the year 1998 (Coillte 1999) on the basis of the conversion factors used.

The model indicates a considerably higher total forest carbon store in the Republic for the year 2000 (18.2 M t C) than the 10.7 M t C reported by Cruickshank et al. (2000) on the basis of CORINE land cover (including scrub and discontinuous trees). The model described here excluded areas of young plantation not identified by remote sensing and assumed a higher carbon content fraction than Cruickshank et al. (2000), although the basic densities and BEFs are similar. Some of the scrub, which was derived from the 1971 inventory of private woodlands (Purcell 1979), will have disappeared through clearance and land reclamation. Some will have been recorded by FIPS as broadleaved forest. The average forest biomass carbon stock in our model for the year 2000 was 39.6 t C ha^{-1} for the productive areas of forest estimated by Cruickshank et al. (2000) or 24.7 t ha^{-1} when the areas of scrub and discontinuous trees (taken from the Corine classification) are included.

Discussion

The higher carbon storage estimates for the Republic determined here compared with those in Cruickshank et al. (2000) warrants further comment. The higher per ha carbon stock may be explained by the use of 0.5 as the carbon fraction of dry wood biomass (IPCC 2004) compared with a range of 0.42 – 0.46 used by Cruickshank et al. (2000).

The area of young and mature forest in the present approach for 2000 is 0.459 m ha and all classified forest land is 0.650 m ha compared with the CORINE area of 0.299 m ha productive forest and 0.432 m ha of forest, scrub and discontinuous trees. These differences would therefore explain the significantly greater total carbon stock for the year 2000 reported here. A more detailed breakdown of species may have also contributed to this result. Overall it would appear that, for the options assumed here, the time series gives a realistic estimate for carbon and stock changes in the national estate for the period under consideration.

Although the total carbon stock in the national estate is increasing and the trend of net storage is also upwards, this pattern is uneven. This probably reflects changes n annual planting programmes and their movement from unclassified to young forest in the model. It may also be noted that clearfelling reached a high level in 1999, which also coincides with a dip in the increase in net annual storage from 0.28 to 0.21 M t C. Felling was lower in 2000 which resulted in an increase in net carbon storage.

Forest soils

Measuring and predicting changes in soil carbon stocks is extremely difficult. This is mainly due to high spatial variability and the fact that changes are usually very small relative to the total carbon stock. Carbon stored in forest soils is estimated to be a very significant component of the forest ecosystem storage (Byrne 2001). An estimate of the average carbon store in forest soils is 305 t C ha^{-1} (COFORD 2001). Taking this into account suggests that the total carbon stock in the national estate may been 112 M t in 1990 and increased to 137 M t in 2000 (areas under forest cover only).

Using the model

The model presented here represents an interim step in the development of a forest carbon accounting system. It has a degree of flexibility and can be adapted as new information becomes available. Changes can be made to all conversion factors relating to a stocking, species volume per ha, planting and clearfelling and factors used to convert commercial wood biomass to carbon.

The assumption made that young crops reflect conditions from age 7 onwards may not represent conditions on the ground in 1995 and underestimate carbon stock if crops were older so options for ages up to 10 years and over can be chosen. Assumptions made with regard to volumes and forest biomass are conservative.

The model can be extended from 2000 on, distinguishing between all forests and those planted from 1990 onwards, using either actual planting rates or assumptions to evaluate the impact of various planting and felling policies on future carbon storage. For example, an adjustment of predicted clearfelling levels can indicate the threshold which would result in no net carbon storage in older forests.

Improving the model

Accurate, up-to-date information is essential for realistic carbon stock estimates and predictions, so the completion of a full national inventory is a highly important part of the reporting process. When this inventory is completed the model can be revised by including up-to-date planting and felling data, age and species distributions, volumes, increments and stocking levels.

In the model, crops under 7 years of age were considered to have no net carbon sequestration below this age. The results of the COFORD-funded CARBIFOR project will help to clarify the situation as far as those crops are concerned.

A large area of FIPS was classified as cleared. This includes actual clearfelled areas, newly planted areas or otherwise unidentified areas. The provision of afforestation and reforestation dates through the Forest Service planting grant system, across the species categories defined by FIPS would provide more complete information on very young crops and their progress over time to the other crop development categories.

The work has also highlighted the need for more information on both thinnings and clearfelling by species in the private sector. Information on areas clearfelled would be particularly useful in using the model for future prediction. This could be recorded through the Forest Service felling licence system.

Acknowledgements

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Appendix 1

Operation of the model to determine forest areas in the FIPS categories forwards and backwards from 1995

The changes in forest classification over time shown in Figure 1, Appendix 1 below.

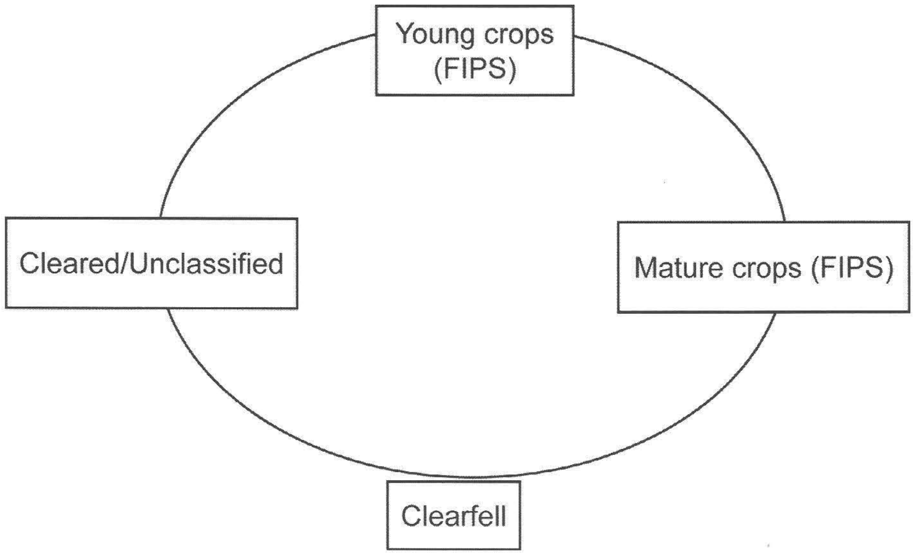

Figure 1, Appendix 1. *The harvest/regeneration cycle and associated changes in forest classification.*

The assumptions used to assign to the three different categories were:

1. Afforested and reforested areas 7 years and over, defined as cleared/unclassified in FIPS move each year into the young crops category. Areas were derived from Coillte felling and Forest Service planting records.
2. 5.6 percent of the young crop category moves each year into the mature category (at 25 years). This means that there is a full turnover of these crops every 18 years.
3. Mature crops are clearfelled and these areas come back to the cleared/unclassified category.
4. For the purposed of the model clearfell is defined as Coillte felling plus a representative 200 ha of private felling.
5. Clearfell is presumed to equal the following year's reforestation
6. The process works forwards or backwards from FIPS base year 1995.

Examples

Young crops

1995 ha = FIPS ha for 1995 for a given category

1996 ha = (1995 ha + (afforestation 1989 + reforestation 1989) x species %) – 1995 ha x 0.056

1997 ha = 1996 ha + (afforestation 1990 + …

1994 ha = 1995 ha – (afforestation 1988 + reforestation 1988) x species % + 1995 ha x 0.056

1993 ha = 1994 ha – (afforestation 1987 + …

Mature crops

1995 ha = FIPS ha for 1995 for a given category

1996 ha = 1995 ha + (1995 young ha x 0.056) – clearfell 1996

1997 ha = 1996 ha + (1996 young ha x …

1994 ha = 1995 ha – (1995 young ha x 0.056) – clearfell

1993 ha = 1994 ha – (1994 young ha x …

Appendix 2

Carbon stocks, annual net carbon increment and harvest from forests in the Republic of Ireland for 2000 using a modified Table 5a (common reporting format approach).

Table 1, Appendix 2. *Carbon stocks, harvest and increment in Irish forests for the year 2000 according to United Nations Framework Convention on Climate Change, Common Reporting Format, Table 5a format.*

		Area	*Stemwood Overbark*	*BEF*	*Basic density*	*Total tree biomass*	*Carbon content*	*Carbon*	*Total carbon*
		ha	m^3	$t\ t^{-1}$	$t\ m^{-3}$	$t\ dm\ ha^{-1}$	$t\ t^{-1}$	$t\ C\ ha^{-1}$	*t*
Plantation	*Quercus*	5921	207.73	1.6405	0.55	187.43	0.5	93.72	554919
	Fagus	3336	204.22	1.6405	0.55	184.26	0.5	91.13	307364
	Other BL	51885	118.56	1.6405	0.55	106.98	0.5	53.49	2775260
	BL Total	61142							
	Pinus	93539	96.93	1.6405	0.40	63.60	0.5	31.8	2974740
	Picea	247048	125.49	1.6405	0.35	72.05	0.5	36.03	8900277
	Other CF	24141	121.88	1.6405	0.41	81.98	0.5	40.99	989583
	CF Total	364728							
	Mixed	30914	127.76	1.6405	0.48	100.61	0.5	50.30	1555057
	Other	1900	127.20	1.6405	0.55	115.04	0.5	57.52	109289
	PLT Total	458884							

Total Growing Stock 2000 (Gg C) 18145492
($Gg\ CO_2$) 66533471

Total Growing Stock 1999 (Gg C) 17885113
($Gg\ CO_2$) 65578746

Annual Increment after Harvest 1999 – 2000 (Gg C) 260379
($Gg\ CO_2$) 954724

	Stemwood overbark	*BEF*	*Basic Density*	*Total DM*	*Carbon content*	*Carbon release*
	m^3	$t\ t^{-1}$	$t\ m^{-3}$	*t*	$t\ t^{-1}$	*t*
Biomass Removed in Commercial Forest	3008451	1.6405	0.3702	1826877	0.5	913448
Traditional Fuelwood Consumed						
Total Other Wood Use						
Total Biomass Consumption from Stocks					*(Gg C)*	913448
					($Gg\ CO_2$)	3349312
Net Annual Carbon Uptake/Release (+/-) (Gg C)						
Net CO_2 emissions/removals (+/-)($Gg\ CO_2$)						

Improved estimates of biomass expansion factors for Sitka spruce

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Abstract

Allometric regressions for estimating forest biomass were developed and used to predict changes in biomass expansion factors (BEF) for a Sitka spruce chronosequence. Cross validation of the biomass models obtained from a USDA inventory data base and an Irish biomass data set indicated that stand and regional-specific allometric models need to be developed due to the influence of different management practices or climatic conditions. Analyses of the algorithms suggest that DBH, tree height and stand density should be used as inputs for biomass and BEF models to reduce the error of estimate. Based on the analyses presented in this work, BEF values could vary from 1.4 to 5.0 for a selected chronosequence depending on age, yield class and total stem biomass. Our results also suggest that recent carbon sequestration predictions for Sitka spruce forests may have been underestimated by 2 to 4-fold due to an underestimation of BEF, particularly for afforested stands planted since 1990.

Key words: Biomass expansion factors, Sitka spruce, allometric regression

Introduction

Forest soils and vegetation comprise an important part of regional and global carbon (C) pools. Changes in the size of these pools due to forest succession, disturbance and management practices may result in significant changes in the sinks for C or atmospheric levels of carbon dioxide. The advent of the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol has increased the need for accurate inventories of forest C storage and sequestration. While standardised C inventory methodologies have been developed by the Intergovernmental Panel on Climate Change (Houghton et al. 1997) there is a clear need for studies to reflect national circumstances. There are many uncertainties in estimates of forest biomass C pools, such as the amount of forest biomass (Schroeder et al. 1997, Brown et al. 1997), the appropriate biomass expansion factors (Brown 2002), and values for biomass density and carbon fraction (Lowe et al. 2000).

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Studies on the sink capacity of Irish forests are limited. It is estimated that the average rate of carbon sequestration by Irish forests is approximately 3.36 t C ha^{-1} yr^{-1} (Kilbride et al. 1999), based on the model developed by Dewar and Cannell (1992). However, this estimate of the sink capacity of Irish forests is based on a single biomass expansion factor (BEF) value of 1.3 t t^{-1} for all species, age and yield classes (Kilbride et al. 1999) and ignores the below ground component. Since the allocation of biomass between different forest components is dependent on stand density, forest species and nutritional status, current national estimates of sink capacity would be improved using classified age and species-specific BEF values that include the below ground fraction.

By definition, BEF (the ratio of above ground biomass to merchantable timber volume) may not be suitable for calculation of C storage in forest ecosystems because of the exclusion of younger, smaller trees (DBH < 7 cm). To incorporate younger stands of a chronosequence into current BEF estimates, BEF has to be redefined as the ratio of above ground biomass to growing stem volume (Schroeder et al. 1997). While BEF values expressed on a mass to volume basis are useful for the conversion of growing stem volumes to forest biomass, the BEF value required to calculate C stocks in forests, as set out by the IPPC guidelines (Houghton et al. 1997), is expressed on a mass to mass basis, since biomass densities are included in the calculation. In this study, we include below ground tree biomass in the BEF calculations to enable the determination of total biomass from growing stem biomass.

In addition to their importance for compiling C inventories in forests, biomass estimations are relevant for studying biogeochemical cycles and understanding variations in structural and functional attributes of forest ecosystems across a wide range of environmental conditions and silvicultural practices. While many ecological studies have used allometric algorithms to predict forest biomass (Cannell 1984, Kauppi et al. 1992, Brown et al. 1997, Schroeder et al. 1997 and 1999, Nelson et al. 1999), the accuracy of estimating standing biomass through the development of empirical models is reduced due to many factors. First, few universal species-specific allometric equations have been developed that are applicable at different regional scales or appropriate for different environmental conditions. Second, since most models are parameterised using national inventory data, estimates are generally limited to older age classes. Consequently, the application of models to younger stands may lead to errors when predicting forest biomass. The prediction of C storage by younger forests, in particular, is important with regard to Article 3.3 of the Kyoto Protocol wherein only that carbon sequestered at sites afforested since 1990 is eligible for the issuance of RMUs (removal units).

The specific objectives of the study were:

1. to develop allometric relationships for the prediction of above ground biomass, below ground biomass and growing stem biomass using inventory data,
2. to validate the empirical models against published data and separately obtained harvest data from trees grown in Ireland,
3. to apply the validated models to Sitka spruce stands for the estimation of biomass and BEF in a 9 to 45-year-old chronosequence and
4. to provide guidelines for the establishment of an improved Irish national forest inventory.

The wider objective of the work reported in this paper is to develop empirical models and to identify the required allometric inputs that will aid in a national C sequestration inventory for reporting to the UNFCCC. We also discuss the implications of using classified BEF values, based on age and yield class for individual species, for the establishment of an Irish national C forest inventory.

Methods

The overall approach was to develop regression equations for estimating above ground, below ground and growing stem biomass. Estimated values were then validated against an independent data set and the best-fit equations were applied to an experimental data set taken from a 9 to 45-year-old Sitka spruce chronosequence. Redefined biomass estimates were then used to calculate a BEF ratio of total biomass to growing stem biomass.

Biomass regression equations

While the best approach for estimating forest biomass on a regional scale is to use data from national forest inventories (Schroeder et al. 1997), Irish forest inventory practice to date has not provided the data necessary to derive the allometric equations required for biomass estimation. Therefore, regression equations were initially derived based on an inventory of ~2000 individual Sitka spruce trees from the USDA Forest Service FIA unit website: *http://www.srsfia.usfs.msstate.edy/scripts/ew.htm*. The database contains information from inventories conducted over a cycle of 10 years. We acquired data from the 1990 inventory for all living Sitka spruce trees with a diameter at breast-height (DBH) of 2.54 to 40 cm growing in the states of Alaska and Washington. Allometric models were developed using data for tree height (H), DBH and total above ground biomass (ADW). The following indicators of goodness of fit for linear, non-linear and log transformed regression models are reported:

1. the coefficient of determination, r^2 of the simple regression or R^2 of the multiple regression,
2. standard error, reported for both the intercept and the partial regression coefficients of the independent variables,
3. the significance level of the t-value, for each independent variable and combination of different variables used in multiple regressions,
4. the average error of estimate, based on the difference between the actual and predicted values and expressed as the modulus of the average percentage deviation.

Regional biomass inputs

Individual components of total biomass, including roots, of a total of 60 trees obtained from published and unpublished data for Irish Sitka spruce (Table 1), were used to derive site-specific allometric equations. The biomass distribution (DBH range) and management history, such as planting densities, of these stands are representative of current national forests, except for the Glenmalure site (Table 1), where the planting density (3700 stems ha^{-1}) was higher than current practice (2500 stems ha^{-1}).

Unless otherwise stated (Carey and O'Brien 1979, Wills et al. 1999), trees were

Table 1. *Forest age, yield class, soil type, stand characteristics and tree dimensions used for the modelling exercise.*

Forest	*Age (yr)*	*Yield class (m^3 ha^{-1} yr^{-1})*	*Soils*	*Stem ha^{-1}*	*Mean DBH (cm)*	*Mean Height (m)*	*Source*
Ballygar	5-7	20-24	Wet gley	2,500	2.6	2.7	Wills 1999; Wills et al. 1999
Lullymore	19	20-24	Industrial cutaway peatland	1300	21	15.2	K.A. Byrne unpublished data
Rossmore	20	20-24	Wet gley	2,500	18	14.3	Wills 1999; Wills et al. 1999
Derrybrien	31	20-24	Gley brown podzol overlaying a gley	2,000	*36*	22.8	Wills 1999; Wills et al. 1999
Glenmalure	33	14	Peaty gley	3,700	17.3	13.8	Carey and O'Brien 1979

harvested that were representative of the mean DBH of a 100 individuals within each site. Branch whorls and inter-whorls were stratified (Snowdon 1986) and sampled systematically after trees were felled. The height of each whorl was recorded and the total fresh weight of each whorl and inter-whorl was obtained using a portable spring balance to a precision of 0.1 kg. Five stem-wood discs were collected at DBH, mid-diameter, 7 cm diameter, 4 cm diameter and halfway between mid-diameter and 7 cm diameter for fresh weight, dry mass and volume determinations. The volume of the stem was calculated assuming a frustum shape (Hamilton 1975), based on the five diameters and height measurements. Roots were manually excavated from a 2 x 2 m trench surrounding the root collar to a depth of 90 cm. Fresh weight was determined for the stump, fine (< 0.3 cm diameter), small (0.3-0.5 cm), medium (0.5-5 cm) and large roots (> 5 cm) which were then sub-sampled for dry mass estimates. All biomass components were oven dried at 70 ºC and weighed after three days when the dry mass was constant.

Biomass, DBH, basal area, tree height, growing stem volume and biomass were used to derive above ground (ADW), below ground (BDW), and stem biomass equations. The same accuracy of estimation and goodness of fit parameters were used as described previously.

Experimental data set

The sites representing the Sitka spruce chronosequence were located in five different Coillte forests in the Portlaoise area (~52º 57' N, 7º 15' W). Selected stands (9- to 45-year-old trees) were representative of the typical yield class (18-20 m^3 ha^{-1} yr^{-1}) for Sitka spruce growing on wet mineral soils in Ireland (Table 2). An additional 14 year-old-stand, with a yield class of 24 m^3 ha^{-1} yr^{-1}, was also selected. Total height (H), height to

Table 2. *Site and tree characteristics of the Sitka spruce chronosequence in the Coillte Portlaoise forests.*

Forest	*Age*	*Yield class*	*Sample plot size*	*Stem* ha^{-1}	*Mean DBH*	*Mean Height*	*Crown to height*	*LAI*
	yr	$m^3\ ha^{-1}\ yr^{-1}$	*ha*		*cm*	*m*	*ratio*	$m^2\ m^{-2}$
*Baunogue**	9	16-20	4 x 0.01	2,300	5.4	3.8	0.08	4.5
*Clontycoe**	14	16-20	4 x 0.01	2,366	10.8	5.8	0.13	7.8
Dooary	14	20-24	4 x 0.01	2,400	13.6	7.6	0.41	10.5
Glenbarrow	25	16-20	4 x 0.03	1,133	22.8	14.9	0.56	8.2
*Dooary**	30	16-20	4 x 0.03	1,083	25.2	17.6	0.59	7.2
*Cullenagh**	45	16-20	4 x 0.03	730	31.4	21.0	0.61	6.5

* One to three random trees were harvested from each of these sites and the biomass data were added to the Irish data set (Table 1) used to derive allometric equations (see Table 5).

crown (HC) and DBH of individual trees from four sampling plots per site was recorded over a period of one week in July 2002. The plot sizes varied from 0.01 to 0.03 ha, depending on the age and management of the site (see Table 2). Tree height was estimated to the closest cm using a laser hypsometer (Laser Technology Inc., Colorado, USA), calibrated against the actual height of selected trees (1-20 m). Height to crown (HC) was defined as the height from the ground to the lowest live branch. Leaf area index (LAI) was calculated using sapwood allometric estimates based on the pipe-model theory as described by Gill et al. (2000). Sapwood area (Asw) was estimated using a regression equation: Asw = 2.37×10^{-5} (DBH^2 HC). Leaf area was then estimated using the linear regression LAI = (0.163 x Asw – 2.594) x stand density (trees ha^{-1}).

Results

Universal species-specific regressions

Scatter plots of data obtained from the USDA web site were used to determine if the three biometric parameters showed a strong relationship with ADW (Figure 1A-C). The plots show a clear non-linear relationship for DBH v ADW, and a similar relationship but with more scatter for H v ADW. Exponential, quadratic and power curves were fitted using the best predictor (DBH) for ADW. The best fit was obtained from a power curve ($y=a\ xX^{\beta}$), giving an r^2 of 0.93 and a β coefficient of 2.71 (Model 1, Table 3). Similarly, the best model for ADW based on H was a power curve (Model 2, Table 3), but with a lower r^2 of 0.89 and a larger variance in the partial coefficient predictors.

Several linear models were fitted to log-transformed data because these functions tend to stabilize the variance and linearise the relationships. However, this did not completely remove the curvature underlying the model (Figure 2) resulting in an

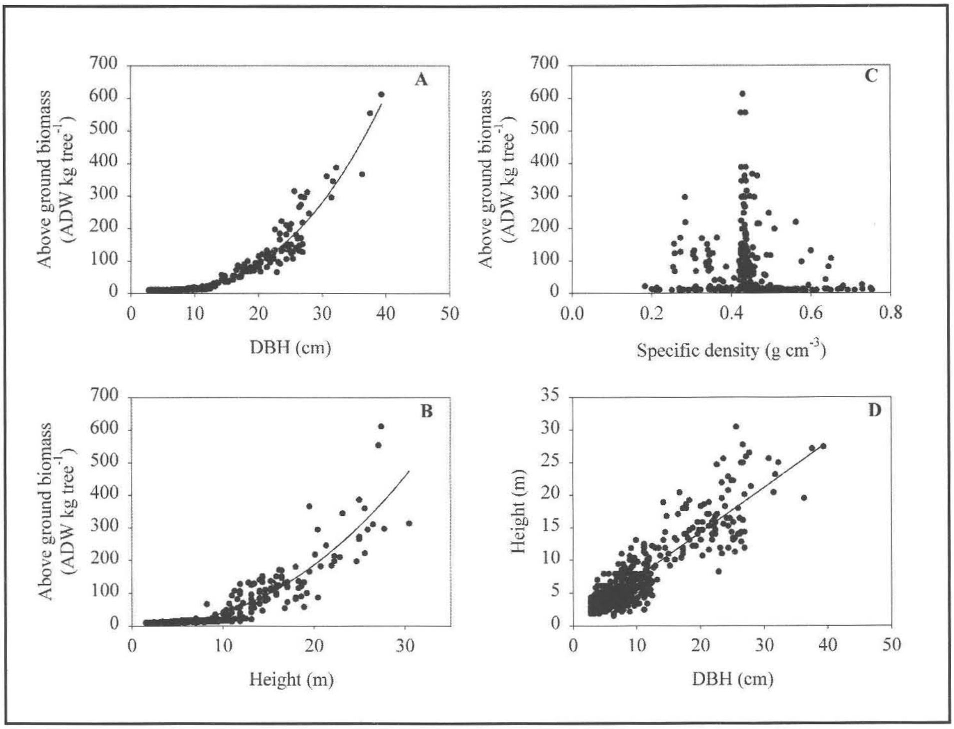

Figure 1. *Relationships between DBH (A), tree height (B), specific density (C), and above ground biomass (ADW). Panel D illustrates the linear relationship between DBH and tree height. Data were obtained from the 1990 USDA inventory data base of selected trees with a DBH varying from 2-41 cm.*

Table 3. *Regression models for estimating above ground biomass (ADW) based on USDA inventory data. Trees range in size from 2 to 40 cm DBH.*

Regression model	*Coefficient symbol*	*Coefficient value*	*t-value*	*Standard error*	r^2	*Standard error of estimate (%)*
1) ADW= αDBH^{β}	α	0.028	11.8	0.002	0.93	16.1
	β	2.71	101.1	0.026		
2) ADW= αH^{β}	α	0.23	9.5	0.026	0.85	24.1
	β	2.22	63.5	0.035		
3) ADW= $0.5+15000(DBH^{\beta})/(DBH^{\beta})+c$	β	2.71	18.2	0.037	0.95	2.5
	c	346629	58.6	3524		
4) ADW= $\alpha(DBH \times H)^{\beta}$	α	20.76	70.9	0.290	0.98	8.9
	β	1.39	179.2	0.007		

underestimation of ADW for younger trees. Non-linear, half-saturation functions (Cieszewski and Bella 1989) using DBH as a predictor of ADW significantly increased the correlation coefficient to 0.95, but this also increased the standard error of estimate by 5.3% when compared to model 1 (Table 3). The coefficient β for this model (model 3) was derived from model 1. The chosen constants, 15000 and 0.5, were based on the maximum asymptotic biomass of a tree and an intercept or minimum biomass (Cieszewski and Bella 1989).

An alternative improvement using non-linear functions was found by adding a second biometric predictor to the equation to account for differences in mass between trees of the same diameter. By adding H as another independent variable to a commonly used multivariable regression ($\ln(ADW) = c+\alpha(\ln(DBH)+\beta\ln(H))$), would result in an increase in R^2, when compared to r^2 (Neter and Wesserman 1974), but because the correlation between the two independent variables is high (Figure 1D), multicollinearity generally causes one or both of the estimated partial coefficients to become less precise (t-values get smaller). A mathematically equivalent derivation of the above equation and one which avoids using log-transformation and multiple regressions with collinear variables, is Model 4 (Table 3): $ADW = \alpha+(DBH \times H)^{\beta}$, obtained from the simple relationship between ADW and DBH x H (Figure 2). Relative to model 1, the standard error of estimate decreased by 7.2% and the estimated coefficients were more precise (t-values larger). The best coefficient of determination ($r^2 = 0.98$) was obtained using model 4 (Table 3).

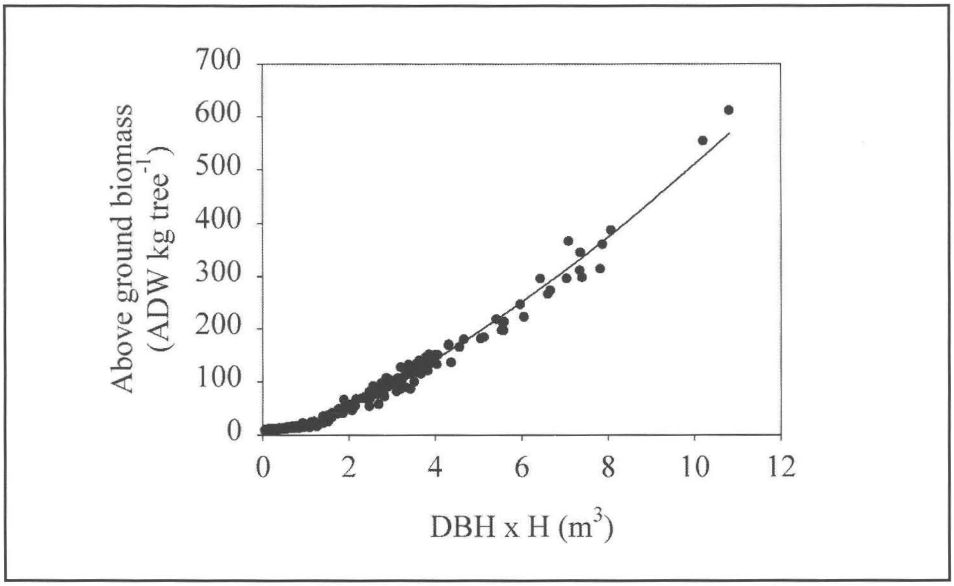

Figure 2. *The non-linear relationship between, the product of DBG and H, and above ground biomass (ADW) in selected trees (DBH 2-40 cm) from the 1990 USDA data base. The exponent from the power curve function was used in Model 4 (see Tables 3 and 5).*

Validation of universal models against an Irish data set

Cross-validation of the models derived from the FIA database against the Irish data suggest ADW was overestimated when DBH was used as a predictor, while H underestimated ADW (Table 4). When both variables were used to predict ADW the slope of the linear relationship (α) between predicted and observed values was close to 1 (Model 4 Table 4). Although this model also predicted ADW of an independent data set with the least variance (F-ratio) and the smallest unsigned error of estimate, the error of estimate was greater than 26% (Table 4).

Another problem associated with the use of the FIA inventory data to predict BEF over a chronosequence was the limited information on total stem biomass and below ground biomass (BDW). Biomass equations were, therefore, modified using the Irish data set.

Table 4. *Validation of models derived from the USDA data against an Irish data set. Correlation coefficients (r^2), F ratios for correlation, slope, t-value of the predicted slope and the unsigned standard error of estimate were derived from linear regressions between predicted and actual ADW for 60 harvested trees from the Irish forest sector (Tables 1 and 2).*

Regression model	r^2	*Slope (α)*	*t-value*	*F-ratio*	*Standard Error of Estimate (%)*
1) $ADW = \alpha DBH^{\beta}$	0.89	1.04	21.9	470	35.2
2) $ADW = \alpha H^{\beta}$	0.89	0.69	22.7	517	43.7
3) $ADW = 0.5 + 15000(DBH^{\beta})/(DBH^{\beta}) + c$	0.81	1.55	22.6	509	64.2
4) $ADW = \alpha(DBH \times H)^{\beta}$	0.91	0.98	26.4	606	26.1

Region-specific equations

Scatter plots and allometric relationships for DBH, H and ADW for the Irish data set were derived using the same procedures as described for the universal data set (Table 5). Best fits for ADW based on DBH were also found to be power functions, although the coefficient of β for Sitka spruce in this case was 1.63, compared to 2.71 for the USDA data (Tables 3 and 5). The best coefficient of determination (0.97), the smallest standard error of estimate (18.6%) and the most precise estimated coefficients were obtained using model 4 (Table 5).

In addition to ADW, algorithms were also derived for below ground biomass (BDW) based on DBH. Whilst DBH was a good predictor of BDW (Model 5, Table 5), giving an r^2 of 0.94, the error of estimate was large (27%) due to variations in root biomass with trees of a similar DBH. This was particularly true for larger trees, as they are probably older and have had more time to exploit the available resources (Figure 3A). Theoretically, an allometric relationship between a measured ADW and BDW should be, and was (data not shown), significant due to a linear increase in shoot to root ratio over time, but this was not a feasible input parameter to use, as inventories do not report on shoot to root ratios. An alternative model tested was the linear relationship between predicted ADW, based on the best fit from Model 4, and BDW (Model 6). However, a large standard error of the intercept (c) and a low probability (60% confidence level) of the t-value for c resulted in an increase in the error of estimate by 13% (Table 5). The same linear model was then fitted to log-transformed data to stabilize the variance (Figure 3B and C). In contrast to ADW linearised models, any curvature underlying the model was not evident after log transformation of the predicted ADW and BDW data (Figure 3C). In addition, the best fit was obtained using Model 7, giving an r^2 of 0.98 and the lowest error of prediction of 20.1%.

Based on the data presented in Table 5, the best predictors for ADW and BDW were models 4 and 7, respectively. These models were combined to give an estimate of total biomass (TBIOM):

$$TBIOM = [53.96\ (DBH \times H)^{0.93}] + [0.9 \ln\{53.96\ (DBH \times H)^{0.93}\} - 1.29]$$

Table 5. *Regression models for above ground (ADW), below ground (BDW) and stand growing stem biomass (SSDW) based on the Irish data. Tree DBH varied from 2 to 37 cm.*

Regression model	*Coefficient symbol*	*Coefficient value*	*t-value*	*Standard error*	r^2	*Standard Error of Estimate (%)*
1) $ADW = \alpha DBH^{\beta}$	α	1.48	4.88	0.23	0.97	20.4
		1.63	26.99	0.06		
2) $ADW = \alpha H^{\beta}$	α	1.06	3.08	0.35	0.92	33.7
		2.22	63.5	0.03		
3) ADW=	β	1.63	18.2	0.03	0.95	23.5
	c	214568	58.6	3524		
4) $ADW = \alpha (DBH.H)^{\beta}$	α	53.69	17.69	3.03	0.97	18.6
		0.93	29.99	0.03		
5) $BDW = \alpha DBH^{\beta}$	α	0.39	4.10	0.09	0.94	27.1
		1.37	18.61	0.07		
6) $BDW = \alpha(\text{ADW model 4}) + c$	*c*	0.55	0.83*	0.66	0.93	39.0
		0.14		0.04		
7) $\ln BDW = \alpha \ln(\text{ADW model 4}) + c$	*c*	-1.29	-29.95	0.04	0.98	20.1
		0.90	72.51	0.01		
8) $\ln SSDW = \alpha \ln(H.G) + c$ *(DBH<7cm)*	*c*	-0.39	-5.11	0.07	0.87	26.4
		0.87	11.03	0.04		
9) $\ln SSDW = \alpha \ln(H.G) + c$ *(DBH>7cm)*	*c*	-1.65	-3.52	0.28	0.84	27.2
		0.99	9.45	0.11		

* indicates the t-value is not significant ($p \leq 0.05$)

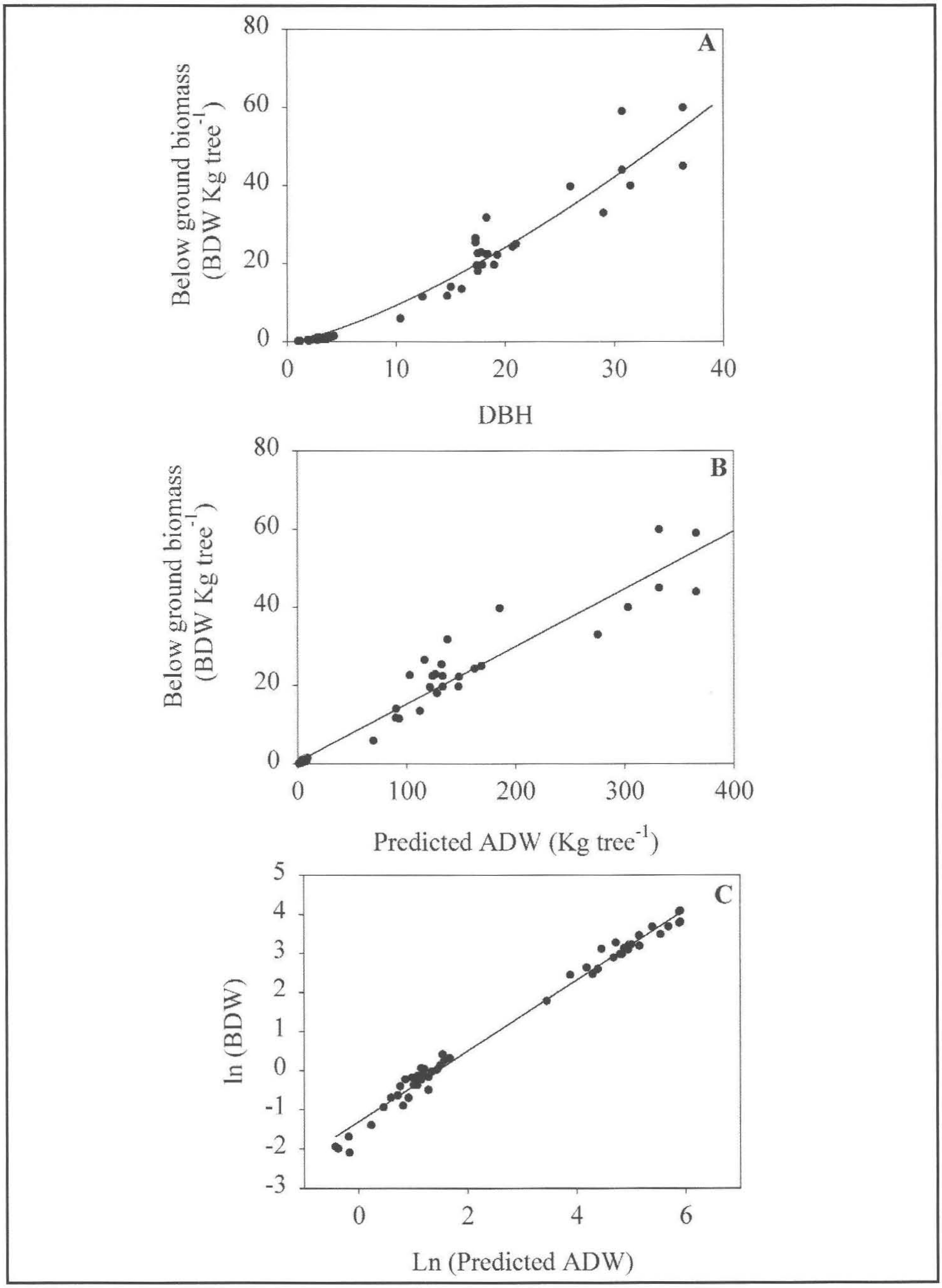

Figure 3. *The relationships between DBH (A), predicted ADW (B, C) and below ground biomass (BDW). The log-log transformation of predicted ADW and BDW (C) illustrated that there was no curvature underlying the relationship. Data were obtained from trees harvested from Irish forests (see Tables 1 and 2).*

Analysis of the residuals of predicted versus observed TBIOM values (Figure 4A) showed an overall error of estimate of 21%. Although there were larger errors associated with predictions for older trees (DBH > 10 cm), compared to young trees, there was no bias towards over or under estimation of TBIOM for the whole data range (Figure 4A).

The estimation of total stem biomass per ha (SSDW) was based on an allometric regression of the form SSDW= F(HG)D (Cannell 1984); where F is a stand form factor, H is tree height, G is over bark basal area and D is specific wood density. The algorithm was simplified to the form ln(SSDW)= ln(HG), since most inventory data would not report on stand specific F or D values. Analysis of the Irish data set revealed that F (0.4-0.8) and D (0.2-0.6 g cm^{-3}) values varied depending on stand age and the ratio of merchantable stem to total stem biomass. Therefore, separate regression equations for SSDW were developed for young and old stands (Table 5). The standard error of estimate (~27%) was higher and the coefficient of determination (~ 0.86) was lower for SSDW, for young and older stands compared to those for ADW and BDW. This was caused by the smaller data sets associated with the separate analysis of young and older stands. However, analysis of residuals showed that there was no bias towards young or older stands (Figure 4B).

Calculation of BEF

The residuals for the predicted and observed BEF values from the Irish data set showed a standard error of estimate of 21% with no bias toward either an over or an under estimation for younger or older stands (Figure 4C). Best-fit models for TBIOM and SSDW were applied to the inventory data from the experimental chronosequence to derive BEF values using models 4, 7, 8 or 9, depending on individual DBH values (see Table 5). The estimated BEF for stands of different age classes showed that it varied from 1.4 to 5.01 t t^{-1} (Figure 5). There was a non-linear decrease in BEF as SSDW increased from 6 to 225 t ha^{-1}, that was best described by the function BEF= $\alpha SSDW^{\beta}$ (r^2=0.92), where α and β are 10.11 and -0.31, respectively (Figure 5). It was also evident that BEF was higher for stands of a higher yield-class, within the same age-class (age-class 14, Figure 5).

Discussion

While there have been attempts to produce general models for the estimation of forest biomass over a wide range of conifer and hardwood forest types (Schroeder et al. 1997, Brown 2002), the application of these models to a stand and region specific scale can lead to large errors in the prediction of forest biomass. For example, the application of a widely used model (Model 3, Table 3) to the Irish data set resulted in an error of estimate of 64% and over estimation of above ground biomass, particularly in older stands of Sitka spruce (Table 4). This may be due, in part, to different management and climatic conditions. Although data from the USDA forest inventory was selected to represent the types of Sitka spruce grown in Ireland, these data are essentially from semi-natural forests where stand densities are seldom higher than 300 trees ha^{-1} (Schroeder et al. 1997, Brown et al. 1999). Clearly, inherent differences in forest stand form, degree of self-thinning, crown characteristics and management practices, necessitate the

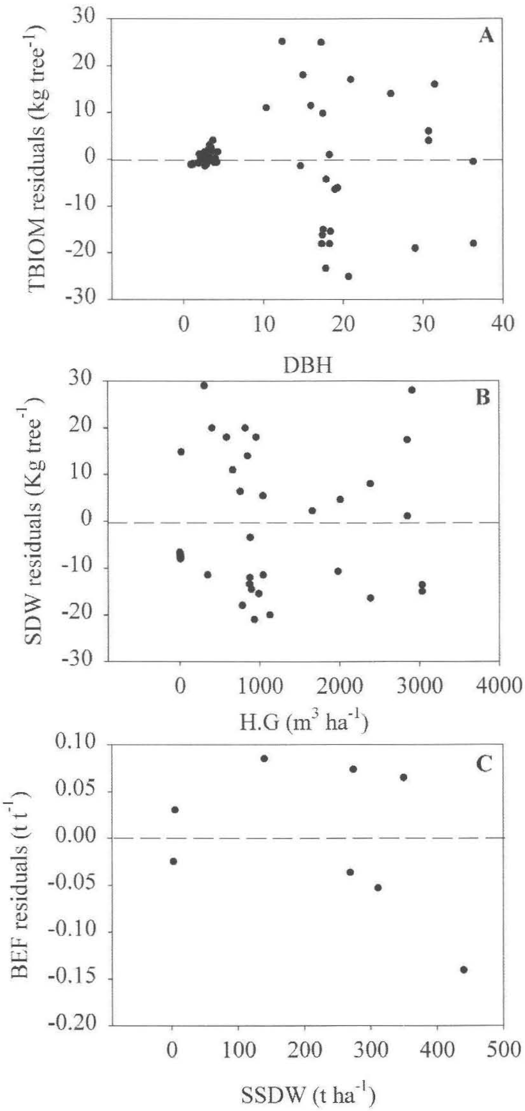

Figure 4. *Residuals associated with the regression equations used to predict total biomass (TBIOM, A), growing stem biomass (SDW, B) and BEF (C). Errors are expressed as signed residuals obtained from predicted and observed values. The tendency of a model to over or underestimate biomass or BEF is indicated by the distance of a point from zero (dashed line). Regression analysis of the residuals and the predictors revealed that no trend was observed, suggesting that the models were not biased toward an over or under estimation of biomass or BEF for either small or larger trees.*

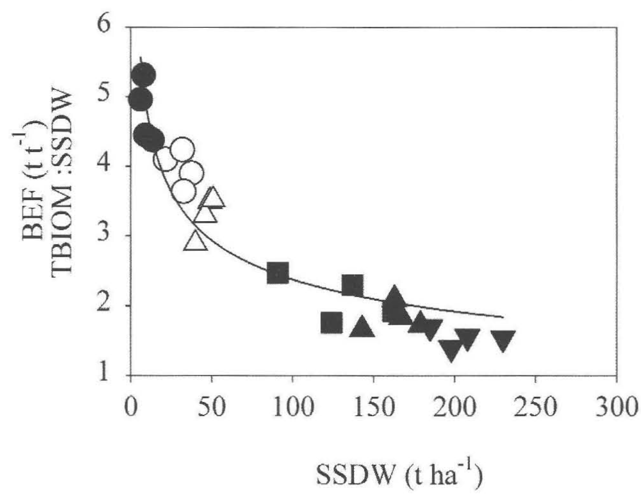

Figure 5. *The non-linear relationship between stand growing stem biomass (SSDW) and BEF, expressed as the ratio between total biomass and growing stem biomass, using data from the Sitka spruce chronosequence. Symbols indicate the age class of stands ● 9 yr-old, ○14 yr-old, △ 14 yr-old yield class 20-24,■ 25 yr-old, ▲ 30 yr-old and ▼45 yr-old stand. All stands were yield class 16-20 unless otherwise stated.*

development of region-specific allometric relationships. This was evident from the differences in the partial coefficients (β) for the power functions obtained from the USDA and Irish data sets (see Tables 3 and 5). The lower value of β for Irish grown Sitka spruce suggests that trees with the same DBH would produce a lower above ground biomass, compared to US grown trees, probably due to higher plant densities and, consequently, a smaller crown area.

It is evident from this study, that at least three essential biometric inputs are required to predict stand BEF, namely DBH, height and stand volume. The inclusion of height as a second independent variable increased the biomass coefficients of determination, whilst significantly reducing the error of estimation by 8 to 3% (Tables 3 and 5), because differences in biomass between trees of the same DBH could be accounted for. This may be important for the prediction of biomass from stands where the relationship between DBH and height may vary due to climatic factors or planting densities. Based on the solutions from model 4, where height was included as a second independent variable in the single regression, the suggestion is that predictions of biomass can be improved when two independent variables are collinear, without decreasing the sensitivity of the partial coefficient predictors (Tables 3 and 5). Other studies (Brown et al. 1989, Overman et al. 1994) have also addressed this problem by using an algorithm of the form ln(ADW)= c + β ln(DBHx H), where the exponent (x) is fixed at 2. However, by arbitrarily fixing the exponent at 2, the partial regression coefficient for ln(H) could be forced away from its ideal value (Nelson et al. 1999) because DBH is a stronger predictor of ADW than height (Tables 3 and 5). Furthermore, two forms of bias exist when using logarithmic transformations. Small variations in the biometric input from small trees can influence the slope and intercept of the linear regression coefficients more than large trees. Secondly, as evident in this study, an inherent curvature tends to underlie the model, even after log transformation. While the estimated error of model 4 for biomass is still high (~20%), when these predictors are used, the magnitude of this error is similar to those reported for other models (Brown et al. 1989, Schroeder et al. 1997, Nelson et al. 1999). Further refinement of the models developed in this study would require larger data sets from individually harvested Sitka spruce trees from stands of different age-classes, as was evident with the larger USDA data set. The requirement for more data from different yield classes may not improve the current biomass models, because allometry does, theoretically, account for differences in tree development (Cromer and Jarvis 1990, Ingestad and Ågren 1991). For example, the 14-year-old stand for the yield class 20-24 m^3 ha^{-1} yr^{-1}, would have a similar biomass and allocation pattern (e.g. BEF value) as a 19-year-old stand for yield class 18-20 m^3 ha^{-1} yr^{-1} (see Figure 5). Therefore, if the allometric relationship covers the biomass range for all stands in a chronosequence, the prediction of biomass or BEF would not be influenced by the yield class, but by the characteristics that underlie tree allometry. Although the above ground to below ground allocation may vary with soil type, the significant relationship between ADW and BDW (Table 5) suggests that the model can be applied to soil types included in our modelling data set (see Table 1). However, more detailed analysis is required to assess the potential variation in BEFs associated with other soil types.

In this study, we have demonstrated an inverse non-linear relationship between BEF and stand stem biomass (Figure 5). These findings are consistent with other studies on a variety of tropical and temperate hardwoods, pines and spruces (Brown et al. 1989, Brown and Lugo 1992, Schroeder et al. 1997, Brown 2002). Generally, BEF values are high at low stand growing stem volumes, or biomass, and decrease to a constant BEF at a high stand growing stem biomass. Whilst the exponential decline in BEF may be associated with changes in biomass allocation in younger stands, such as a greater increment in stem wood, relative to non-woody biomass, the constant BEF in older stands may be due to the interaction between thinning practices and changes in biomass allocation after canopy closure. Alternatively, at high values for stem volumes or biomass most of the total biomass is allocated to the stem resulting in a constant BEF ratio in older stands. It is evident from the changes in leaf area index in the chronosequence examined in this study that there is a more gradual decline in BEF with an increase in stemwood biomass after canopy closure (~14 years, see Table 2 and Figure 5). The implication of these findings may be of importance when devising thinning strategies for adaptive management policies, where the carbon sequestration potential may be maximized without influencing timber production.

Our results suggest that the recent BEF value used to calculate carbon stocks for Irish forests is underestimated (Kilbride et al. 1999), particularly for younger Sitka spruce stands. The use of a single BEF value of 1.3 may result in an ~2 to 4-fold underestimation of current carbon stocks for afforested sites since 1990. However, the BEF values for stands older than 30 years are similar to the current value of 1.3, based on an average BEF of 1.5 and an error of estimate of 21% reported for an age class of 30 years or older. The slightly higher BEF value for older stands found in this study may be due, in part, to the inclusion of all biomass components for the calculation of BEF.

Whilst BEFs are an important component of the current inventory-based methods used to estimate biomass carbon increment, it is evident from this study and others (Lowe et al. 2000) that this may require the development of stand and species-specific BEF values. A possible alternative would be to develop species-specific biomass functions based on allometric algorithms derived from forest inventories over a rotation cycle to estimate total forest biomass increment. The calculation of biomass carbon stock based on biomass functions and carbon content would eliminate the errors associated with the estimation, of stem wood growth rate, BEF and specific wood densities when calculating forest carbon stocks.

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Forest Perspectives

Charcoal production at Bahana, Glencree Valley, Co Wicklow, 1939-1945

Visitors to forested districts like the Wicklow Way area must inevitably become interested in the details of the occupations of those who find a living there. Nowadays there are foresters and forest staff concerned with the actual work of planting, general care and thinning and finally harvesting of mature timber and its transportation to sawmills and board factories.

During World War II there was another dimension to these activities, that of charcoal making. This was a skilful and ancient craft, practised around here at that time and the people who carried it on were an interesting and unusual group. At that time restrictions in the use of very scarce petrol caused the virtual ending of private motoring. Road transport was partly maintained by using Producer Gas to power vehicle engines, which, apart from the fitting of the necessary Producer Gear (which admittedly was rather clumsy), required a minimum of alteration. The raw material used to make this gas was charcoal obtained from wood, for which there was great demand at the time, hence the many charcoal burners found in the more highly forested areas of which, then as now, this part of Co Wicklow was among the most important in the country. The art of charcoal making must have been known in Ireland long ago but by the year 1939 it had been all but lost, so those able to do it were nearly all from the Continent, where it is practised in the traditional way right up to the present day.

Anyone who has read or heard the fairy stories of Grimms or Hans Anderson in their childhood will remember the mention of Charcoal Burners which conjured up strange and rather uncouth people in mysterious dark Northern Forests. These were our ideas on their first arrival in these parts in the early war years.

Those who came around here were all interesting people, most of them originally coming from various parts of Italy or of Italian extraction – but were living in Dublin, mostly shopkeepers and owners of small cafes and restaurants whose business had suffered owing to wartime restrictions and shortages, forcing them to fall back on their old crafts. In this immediate area were Homero Marshetti who came from near Lucca in northern Italy and his uncle Renaldo. Then there was Gino Collini an Austrian-Italian from the Austrian Tyrol, formerly an army ski instructor. He had a young assistant Harry Schneider, a native of Alsace. Amadeo was half Italian and French from Marseilles formerly, according to himself a French Foreign Legionnaire. He made charcoal in the Deer Park, close by Powerscourt.

Homero bought a big stand of scrub timber from us, mostly sally, and spent a couple of years here, living in a wooden three roomed shack in the field which we still call "Marshetti's Field", where he was frequently joined at weekends by his wife and children. Renaldo and Collini mostly operated in the Ballyorney area.

The cutting down and preparing of the wood for burning entailed quite a lot of labour in those pre-chainsaws days as each burner employed three or four helpers so quite a lot of local people gained employment as a result. The timber for conversion to charcoal varied in size from up to eighteen inches diameter [45 cm] to as little as two inches [5 cm], cut into lengths of about six feet [1.8 m] down to three feet [0.9 m] or so. The sites where this took place were level areas, of dry hard soil about fifteen feet [4.6 m] in diameter, with a drainage channel around the circumference. A wooden stake about nine inches [23 cm] diameter and eight feet [2.4 m] in length was then placed upright in the centre of the area and around it the timber for burning was placed, standing upright row after row, the largest pieces first, gradually decreasing in length and size, the small ones fitted into spaces between the larger pieces. Four ducts were left at ground level, spaced evenly around the pile and leading to the central post. These were for the necessary air supply for burning. In this way a large mound of timber, approximately five tons [5 tonnes], was built up, something about the same shape and size of a haycock, for those that can remember such things! Finally the whole thing was covered over by a layer of sods and soil and it was then ready for burning. Then, using a ladder the central post was removed leaving an open chimney or flue connected with the ventilation ducts.

The fire was started by inserting burning material, usually oil soaked rags, into the central area created by the removal of the post. Combustion was controlled by opening or closing the ducts as required using sods for the purpose. Slow burning went on for four or five days and the colour of smoke from the flue and the temperature of the side of the mound, done by hand testing, judged the progress. At the beginning smoke was copious and white, changing to a barely perceptible whiff of blue colour towards the end. The location of a charcoal burning could always be detected from the vinegar-like odour of acetic acid from the reaction. I remember that Homero had a kind of watchman's hut where he used stay up at nighttime during the final twenty-four hours or so. It was his experience, which dictated when the flues were all closed and the fire extinguished.

After a couple of days the heap had cooled sufficiently to allow the sods and soil to be removed and the charcoal revealed, shiny and black but perfect in shape and none of it consumed. It was then broken into lumps and bagged for sale. Marshetti had a partner and agent in Dublin, a Mr Rocca who looked after that side of the business. The whole process was a continuous one of preparing a new pile while burning was in progress at the other, a process requiring managerial abilities as well as technical expertise; it was most interesting and educational to see it in full swing.

I cannot comment on the economics of the business but I think that about 5 tons of wood went to each burning, producing approximately 1 ton of charcoal, which sold at that time for about £30.00 .

Nowadays I believe that charcoal burning is just another industrial process using special kilns with sophisticated instrumentation whose operatives will probably dismiss the old methods as "folk handicrafts" or some such patronising description. But the Wicklow Way and similar places in the country would be even more interesting than they are at present if people with the same kind of knowledge, skill and calibre as Homero Marchetti and his colleagues of half a century ago were still carrying on this and other rural occupations.

Brian P. Hogan, Mount Maulin, Bahana, Enniskerry, Co Wicklow

(Passed to Aeneas Higgins by the late Brian P. Hogan, 27 June 1990)

Trees, Woods and Literature – 28

Hatsue found herself walking in the woods later that afternoon. It was getting on toward the end of February, a time of only bleak light. In spring great shafts of sun would split the canopy of trees and the litter fall of the forest would come floating down – twigs, seeds, needles, dust bark, all suspended in the hazy air – but now, in February, the woods felt black and the trees looked sodden and smelled pungently of rot. Hatsue went inland to where the cedars gave way to firs hung with lichen and moss. Everything was familiar and known to her here – the dead and dying cedars full of punky heartwood, the fallen, defeated trees as high as a house, the upturned root wads hung with vine maple, the toadstools, the ivy, the salal, the vanilla leaf, the low wet places full of devil's club. These were the woods through which she had wandered on her way home from Mrs. Shigemura's lessons, the woods where she had cultivated the kind of tranquillity, Mrs. Shigemura had demanded. She'd sat among sword ferns six feet tall or on a shelf above a vale of trilliums and opened her eyes to the place. As far back as she could recall the content of her days there had always been this silent forest which retained for her its mystery.

There were straight rows of trees – colonnades – growing out of the seedbed of trees that had fallen two hundred years before and sunk and become the earth itself. The forest floor was a map of fallen trees that had lived half a thousand years before collapsing – a rise here, a dip there, a mound or moldering hillock somewhere – the woods held the bones of trees so old no one living had ever seen them. Hatsue had counted the rings of fallen trees more than six hundred years old. She had seen the deer mouse, the creeping vole, the green-hued antlers of the white-tailed deer decaying under a cedar. She knew where lady fern grew and phantom orchids and warted giant puffballs.

Deep among the trees she lay on a fallen log and gazed far up branchless trunks. A late winter wind blew the tops around, inducing in her a momentary vertigo. She admired a Douglas fir's complicated bark, followed its grooves to the canopy of branches two hundred feet above. The world was incomprehensibly intricate, and yet this forest made a simple sense in her heart that she felt nowhere else.

From *Snow Falling on Cedars* by David Guterson (chapter 14, pp 178-179). Bloomsbury Publishing, London, 1995. *Snow Falling on Cedars* won the PEN/Faulkner Award in 1995. Reproduced by kind permission of the publishers.

Guterson's novel is set in San Piedro Island, off the Washington Coast in the Pacific North West in December 1954. Hatsue is a 31-year-old Japanese-American and wife of Kabuo Miyamoto who is accused of the murder of a fellow fisherman. While the novel is essentially a murder mystery, it is interwoven with sub-plots that concern the lives of people on the tiny island who are struggling with survival, identity and love. It is set against a backdrop of post Second World War suspicions and mistrust between islanders and the Japanese community, mainly fuelled by the hysteria that followed the bombing of Pearl Harbour.

The extract looks back to when Hatsue was 18 years old and in love with Ishmael Chamber, the local reporter who is now covering the trial some 13 years later.

Hatsue had visited the woods to help her make sense of her world and identity. Beneath her outwardly serene countenance, she is in turmoil having had an argument with her mother who reprimands her for a pro-American outburst. Her mother has employed Mrs Shigemura to teach her Japanese customs with the intention that she *would not forget that she was first and foremost Japanese.* Hatsue however identifies with western culture, but at the same time Japan ... *pulled on her and lived inside her despite her wishes to the contrary; it was something she could not deny.* The forest not only provides her with the solitude to confront these conflicting emotions but is also where she meets Ishmael in secret. This is the last time they meet as lovers; shortly after Hatsue and her family, along with thousands more Japanese-Americans are rounded up and interned after the bombing of Pearl Harbour.

Guterson meticulously researches his books to understand and bring to life the landscape and the characters that frequent his novels such as loggers, fishermen and – in the case of *Snow Falling on Cedars* - the Japanese-American people. He carried out many interviews with Japanese-Americans to know how it was to have lived during the 1940s, especially in the internment camps. (Some 110,000 Japanese-Americans were interned during the Second World War. The US government formally apologised to Japanese citizens in 1988 for this wrongdoing.)

Guterson was born in Seattle in 1956 but has had a strong affinity with the forests, mountains, rivers and canyons of Washington State where his novels including East of the Mountains and *Our Lady of the Forest* are set. As a student he worked with the US Forest Service where he says he spent his time burning slash in clearcuts, piling brush, maintaining trails and fighting wildfires. He now lives in Bainbridge Island in Puget Sound. Guterson's landscape will have resonances for Irish readers, especially foresters, timber growers and tree breeders who have visited Washington or who have planted trees which originated in the region.

(Selection and note by Donal Magner)

Book reviews

Farming in Ireland - History, Heritage and Environment. John Feehan. Layout and Design, Bernard Kaye. Printed by Walsh Printers, Roscrea. 605 pp, €80, hardcover. ISBN 1-902277-597.

The first thing (and perhaps the most important thing) to say about this book is, that it is an extraordinary work, which not only covers many of the historical, heritage and environmental aspects of agriculture from the Ice Age to the present day, but also includes amazing arrays of information on geology, archaeology, ecology, meteorology and mythology. All of this is woven by the author into a tapestry of Ireland's natural history, interspersed with poetry, anecdotes, tables (32), plates (8) and figures (272). Much of this is drawn from an estimated 1033 published papers, books and reports. It is an astounding compilation in which the depth of knowledge of the author shows on every page. I find it very easy to believe him when he writes in the Preface and Acknowledgements: "I think this book started when I was nine or ten years old..."

In the opening chapters, (Chapters 1 to 6, pages 1 to 136) Feehan traces the development of farming in Ireland and Europe from the retreat of the glaciers until Ireland's entry to the European Economic Community (EEC). These are followed by chapters on Agricultural Education, Farming Practice, Trees and Woods on the Farm and Field Boundaries. There are also chapters on the animals and plants (domestic and wild) commonly found on Irish farms through the centuries. In these latter chapters, the author has used his very extensive knowledge of ecology to produce a fascinating account of the evolution of agriculture in Ireland. In addition, there is a chapter (Chapter 12) dealing with the imprint of agriculture on the rural landscape, which includes sections on such diverse features as ringforts, traditional farmhouses, steam engines and cultivation ridges. Surprisingly, the history and management of field boundaries is presented in a separate chapter. Chapters 15 to 18 are quite different in style and content to the earlier ones. While they have a historical flavour, they are much more botanic and/or scientific in nature. The ecology and biological diversity of a range of habitats (The Burren, Callows, Turloughs, Eskers, Arable Land, Freshwater Habitats, Mires, Heaths and Coastal Land) is described in general. These chapters and sections contain significant tables of botanical terminology and substantial figures detailing relationships such as food chains and ecological classifications. A central theme in these chapters is the very adverse impact of agricultural intensification upon the diversity of the flora and fauna of the countryside. The author attributes this to loss in diversity of habitat. In the final chapter this decline in diversity and the consequent shrinkage of the genetic base is further elaborated. An alternative system of "Integrated Mixed Farming" is outlined. The author proposes that this system would enshrine all of the best values of rural landscape and rural community and would be sustainable in the long term.

Given the enormity of the work undertaken by Feehan in producing this book and the wealth of knowledge he displays in so doing, it may seem churlish to carp about certain aspects of the work. However, the uneven treatment of topics should be mentioned. Thus, the early chapters seem eminently suitable for a general readership with an interest in history or farming in ancient Ireland. By contrast, much of the material in Chapters 15, 16, 17 and 18, such as that contained in Table 15.11 on "The plant communities of lowland cultivated grasslands" or the details of the biological monitoring of freshwater biota (Table 17.3 page 483), is certainly beyond the capabilities of most general readers, farmers and students, and may tax the technical expertise of many scientists. The Burren is mentioned at least 25 times in this book and aspects of the ecology of the area are covered in two separate sections. On the other hand there is not a single mention in the entire book of the Drumlin belt or of farming in this huge area. In the chapter on animals on the farm, the Shorthorn breed is barely mentioned, while its contemporary, the Rhode Island Red, which was virtually synonymous with farming for many decades, is not mentioned at all. However, while these and other inconsistencies are disconcerting, the major disappointment with this book lies in the poor standard of editing and proof reading. Serious editing would have reduced the size of this book significantly. In this context, one wonders about the contribution to the book of a number of the figures and certainly many of the tables, notably Tables 8.1 and 9.1, could very easily have been presented in synopsised form. There are far too many errors in the book. The quality of English is sometimes colloquial and tenses are often mixed. Apart from the typographical and other errors throughout the text (e.g. "... after accession to the European Economic Community (EEC) in 1963 ..."), there are errors in the referencing, some references are not given, the cross-referencing sometimes breaks-down and metric and imperial units of measurement are used interchangeably. Some tables have no captions or incorrect ones. All of this is a major distraction to the reader.

Notwithstanding my disappointment with aspects of this encyclopaedic tome, this book constitutes a major contribution to agricultural education in Ireland and will be proven to be indispensable to many agriculturalists. It will awaken curiosity and inspire younger generations to seek the wisdom and courage necessary to confront the complex issues which have developed in modern Irish Agriculture as outlined in this book. All serious students of agriculture should study it.

John J. Gardiner

(Dr John J. Gardiner is Emeritus Professor of Forestry at University College Dublin).

A Practical Treatise on Trees by Samuel Hayes. Reprinted facsimile edition (2003) with a foreword by Thomas Pakenham, New Island, 200 pp, hardback, €30. ISBN 1 902602

The full title of the work is *A practical treatise on planting and management of woods and coppices.* Originally published in 1794, it was the first ever book on tree planting in Ireland. This facsimile edition is elegantly case-bound, and is expertly reproduced. Included are the original engravings, illustrations and gatefolds. The endpaper has an image of Avondale House and grounds, taken from the watercolour by DA Beauford, from the late 1700s. It shows the estate with some of the trees planted by Hayes, in an otherwise open landscape.

Most Irish foresters will have heard about this book but few will have read it, as it has been being out for print for almost two centuries. It originally appeared in three editions, first in 1794, followed by two reprints in the early 19th century (both now as rare and valuable as the original). Best known from the book are the fourteen vignettes taken from copper etchings. They appear individually on the title page, tailpieces and in the body of the text. Down the years they have been extensively copied, as copyright has of course long ago expired. They also adorn many another book, including the original guide to Avondale Forest Park.

This facsimile edition is the brainchild of the Irish Tree Society, an organisation set up in 1990 to promote an appreciation of specimen trees. It is reproduced from a copy of the book purchased by the Irish Tree Society at auction in 2000. This particular book has itself an interesting history. It belonged to the late Charles Acton, former music critic of the Irish Times, and one time owner of Kilmacurragh Estate in Co Wicklow. He came into its possession through an ancestor, to whom Hayes presented an autographed copy. The Actons and Hayeses were near neighbours in east Co Wicklow, at Kilmacurragh and Avondale.

Commissioned by members of the Dublin Society (now the Royal Dublin Society) to write a simple guidebook, Hayes wanted to do more than merely instruct people how to plant and manage trees. He said he wanted to inspire his countrymen to love trees. His early death in 1795, only a year after the book was published, cut short what would almost certainly have been an even greater contribution to Irish silviculture. Today, the oldest trees at Avondale including individual beech, oak and larch specimens, the striking Spanish chestnut that frames the house and the two gigantic silver fir by the Avonmore River, are a fitting memorial to Hayes.

Thomas Pakenham's lucidly written foreword puts Hayes in context. If Hayes had not written the book he would have been almost completely lost in the shadows – as it is he remains elusive. He was an Irish MP, barrister, amateur architect, draftsman and passionate planter of trees. These interests are reflected in his work in designing the house at Avondale and planting the estate. A further indication of Hayes's interest in trees is that in 1788 he presented a bill to the Irish parliament with the title *An act for encouraging the cultivation and better preservation of trees.*

The book itself is in two parts; the first provides instruction on tree planting, while part two takes a tour around the estates of the time and describes their specimen trees. This is where history is of help to foresters. It is from the reference to beech at Shelton Abbey that we learn that it was here that it was first planted in Ireland, in the 17th century. Seed from the trees at Shelton was used in other parts of the country.

Mention of beech gives Thomas Pakenham an opportunity to expound on beech being classified as an exotic, which it is. He states "that Hayes noticed that beech seems particularly well suited to Ireland, by contrast, some modern ecologists advocate a kind of ethnic cleansing in which naturalised species such as beech are systematically hunted down and destroyed ". Of course foresters know that to say that beech seems particularly well suited to Ireland needs qualification - to add "... where soil conditions are right and shelter is available or provided."

Pakenham provides a very useful index; the listing of locations shows that Hayes never moved far from the east of Ireland, visiting Meath, Kildare, Kings County (Offaly) and Queens County (Laois). There is one reference to Bellevue, Co Galway, the only one in the West!

Reading the book requires some concentration because, as a facsimile, it retains the 18th century use of f to denote an s. However, after a few pages the reader soon gets familiar with the script.

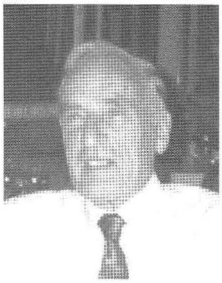
Having a book republished after 200 years is an exciting development. *A Practical Treatise on Trees* will be a revelation to a new generation of foresters and tree enthusiasts. With a print run of 1500 it could soon become as valuable as the first edition!

John Mc Loughlin

(John McLoughlin is Executive Director of the Tree Council of Ireland, and Meetings Convenor of the Society of Irish Foresters.)

Obituary

Christy A McCormack
1914-2004



Christy McCormack who died on the 20 January was a native of Mullingar. He was in his ninetieth year and held an interest in forestry up to the end.

He took a degree in forestry at University College Dublin, qualifying in 1937 from a class of three. Joe O'Carroll, one of the famous O'Carroll brothers who were pioneer foresters in the early fifties and sixties, was a classmate. He spent forty years in various posts with the then Forest Service, ending his career as Assistant Chief Inspector.

It was policy in those days to transfer foresters, sometimes at will, all over the country. Looking back on it now it seems probable that it was a carry-over from the colonial civil service days. It took little account of social or family needs. Christy served first in Wicklow and then in Gort, Co Galway, where he met and married Lilly Broderick. They moved to Sligo, on to Dublin, then to Cork, back to Dublin, Cork again and finally in the 1970s to Dublin where he ended his forestry career.

I met Christy when I took up my first inspector post in Cork in 1960. We quickly became friends as he took me under his wing as a fledgling forester. I found him a shy and deeply private man but he also had a very good sense of humour. Many foresters under his control had reason to be grateful for the gentle way he handled their personal problems.

The staid office routine of 50s and 60s was not conducive to socialising. Against the advice of the senior staff I approached Christy with the suggestion that we should hold a Christmas party and invite all staff in the region. He readily agreed and took part in the organisation with gusto. The era of the forestry social function was born. Many a good social night followed which he and Lilly thoroughly enjoyed. We ran those events for a number of years; even after he was promoted and went to Dublin, he and Lilly continued to travel to events throughout the country.

Christy was first and foremost a family man. Enjoyment for him came with the ease in which he interacted with the staff, their wives and families. He had the luck to have a long life, a happy marriage, four lovely successful children and good health to the end.

To his wife Lilly, daughters Mary, Ann, Colette and son Brian we extend our sincere sympathy.

Go ndeanfaid Dia trocaire ar a anam

ESF

Letter to the Editor

Ballynakillew
Ballinrobe
Co Mayo

Sir

In the early 1990s a recent plantation of Sitka spruce, located in that region of Ireland which has come to be known as the mid-west, was found not to be thriving as would have been expected; in fact it was adjudged a failure. It transpired that the site of the plantation was peaty, underlain by shelly marl.

The condition of some scattered plants of ash suggested that a replanting with that species might prove interesting, and that suggestion was implemented.

Being in the vicinity recently I took the opportunity to revisit the site. I found a crop of thicket-stage ash which appeared healthy and vigorous. A thorough survey of the site was not possible, personal decrepitude being a factor in that regard.

Neither could crop quality be fully assessed, the crop being in full leaf, but what could be seen suggested that the overall quality was no more than moderate.

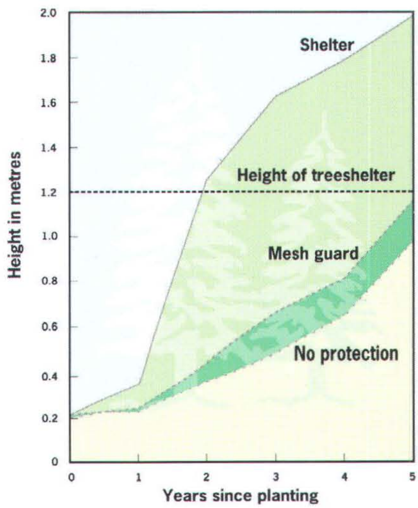
There are several possible reasons for poor crop quality in these circumstances:

i. A deficiency of potassium can lead to loss of apical dominance. Some surviving Sitka spruce trees on the margin of the plantation showed signs of potassium deficiency.
ii. Frost can cause serious forking.
iii. Infestation by ash bud moth (*Prays fraxinella*) kills buds thus causing forking.

Whatever the cause of the sub-optimal quality the relative success of this crop suggests that further survey, followed perhaps by positive experimentation, may eventually suggest a possible solution to the hitherto intractable problem of marl sites.

It may be noted that the problem of 'forestry failures due to shell-marl soil and related conditions' featured in the 1998 Annual Report of the Comptroller and Auditor General.

Yours sincerely
Niall OCarroll



Typical results from Forestry Commission trials showing increased height growth of sessile oak transplants.

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