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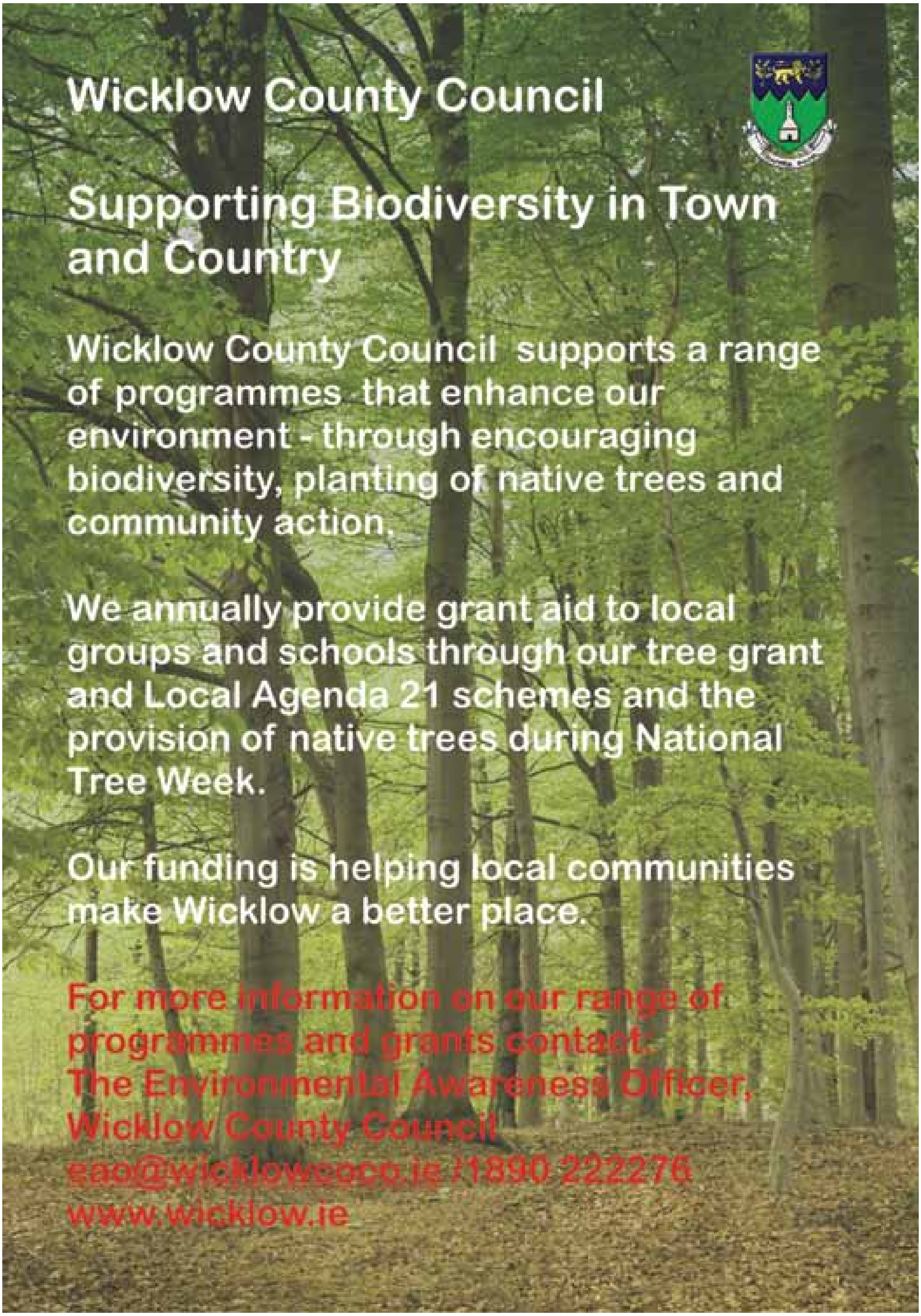
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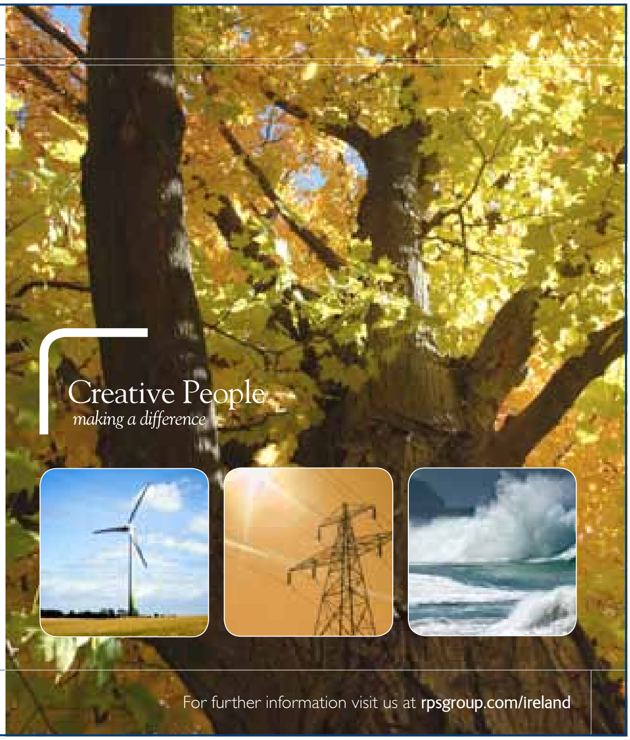
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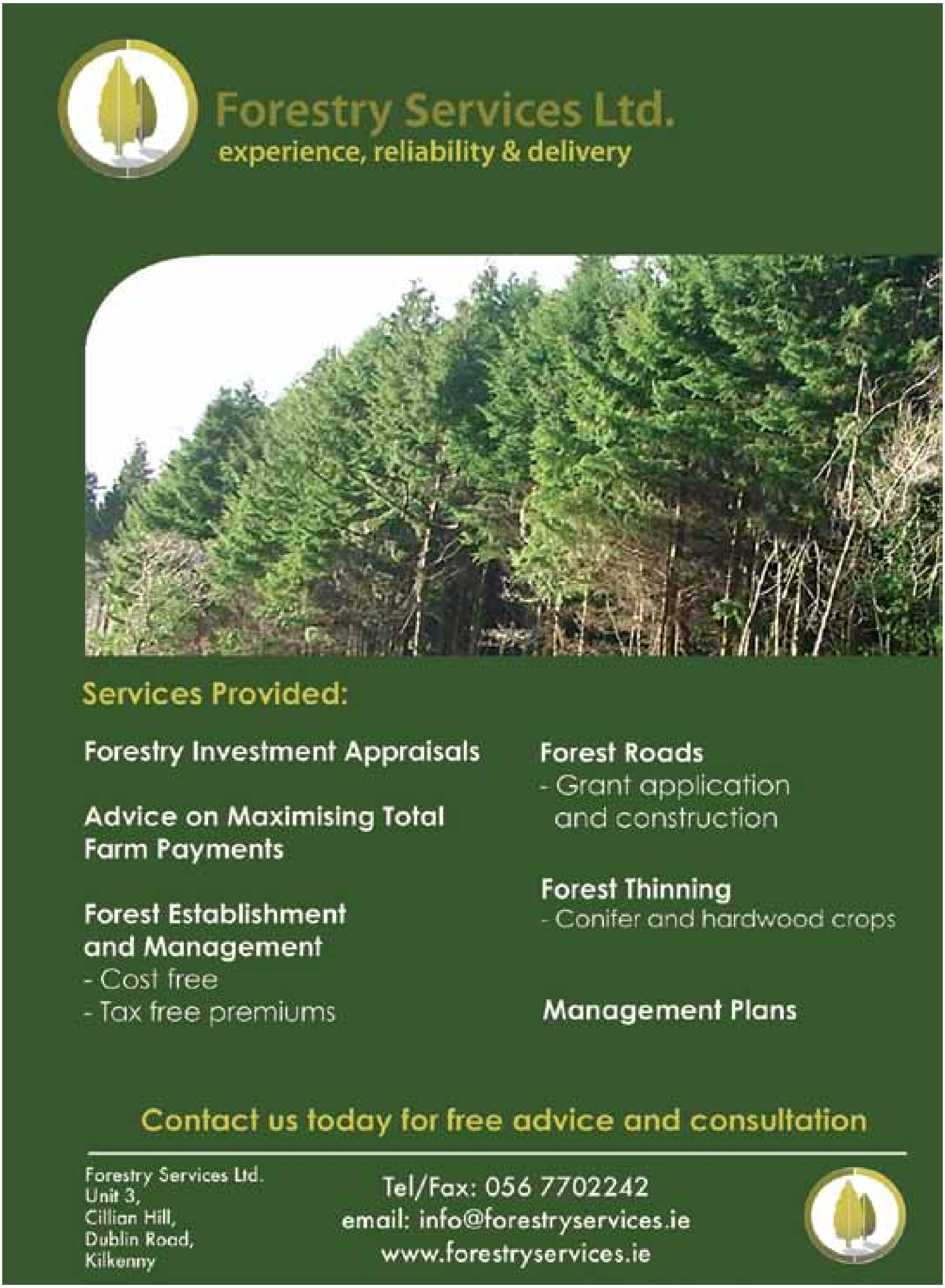
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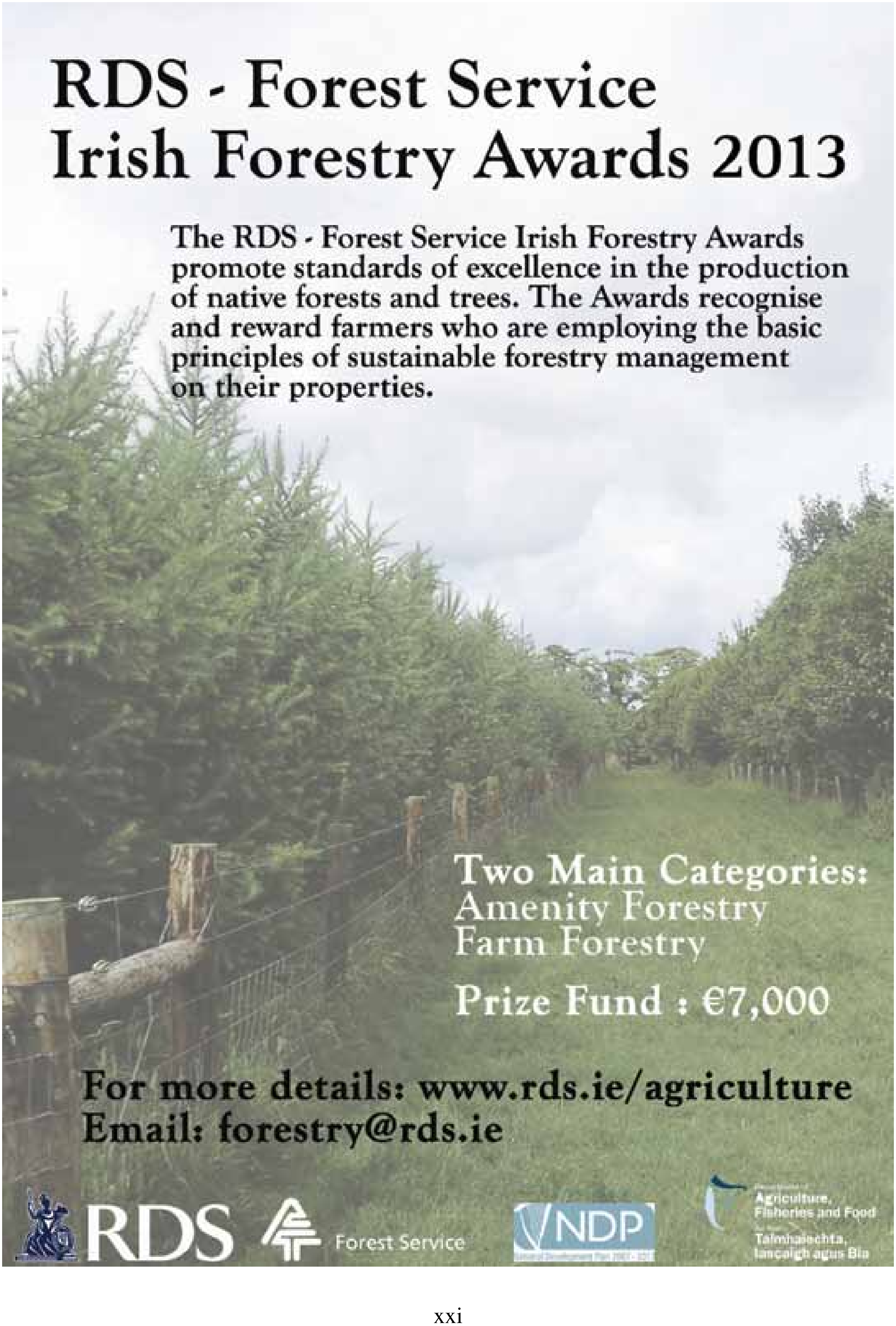
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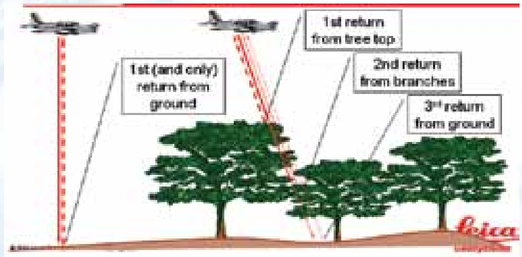

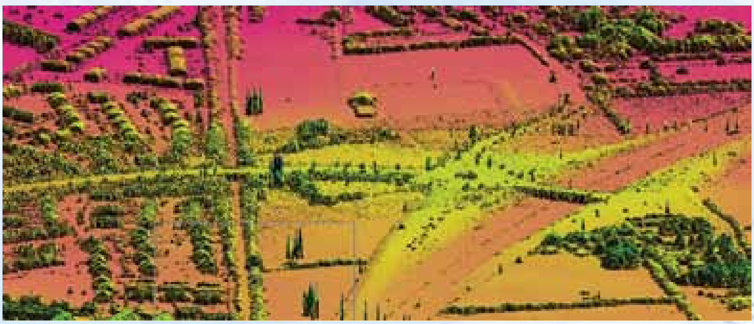

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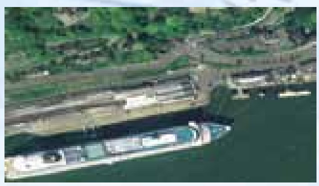

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To lead and represent the forestry profession, which meets, in a sustainable manner, society's needs from Irish forests, through excellence in forestry practice.

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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1. Original material only, unpublished elsewhere, will be considered for publication in *Irish Forestry*. Where material has been submitted for publication elsewhere, authors must indicate the journal and the date of submission.
2. All submissions must be in MS Word, submitted electronially to the Editor, *Irish Forestry* at sif@eircom.net (see Guidelines). Authors are requested to keep papers as concise as possible and no more than 12 pages in length (including tables and figures).
3. Submissions will be acknowledged by the Editor. Authors will be informed if the paper is to be sent for peer review. If peer review is not envisaged an explanation will be provided to authors.
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6. Guidelines for authors on *Irish Forestry* house style and layout can be downloaded as an MS Word template from http://societyofirishforesters.ie/Irish Forestry.

Front cover: Ash-ivy woodland in late spring. *This large ancient woodland is dominated by large oak and ash with pole-sized ash regeneration and a small amount of sycamore (in leaf). The herb flora is dominated by lesser celandine and bluebell. Charleville Estate, Co. Offaly. The photograph was taken by Dr. John Cross.*

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EDITORIAL

Turning a new leaf on broadleaves

This issue contains a large number of papers covering a wide range of topics. In particular, broadleaf species are the main focus of several papers. In a paper commissioned by the Journal, for which we are indebted, Dr John Cross summarises the very large amount of information collected in the National Survey of Native Woodlands in Ireland. Broadleaf species feature heavily in these woodlands. The results highlight the fragmented nature of the resource, but the diversity present in terms of woodland types and plant species-richness is immense. Properly managed, they can also be a valuable and renewable source of raw material.

Broadleaf planting has expanded greatly in Ireland in recent years, with the potential to provide a similarly diverse source of raw materials and services as the native woodlands. However, there will undoubtedly be a much greater focus on timber production in these forests. According to Hawe and Short (this issue), broadleaf planting accounted for 16% of all new planting in 1998 and had more than doubled to 38% by 2010. Some concern has been expressed about the quality of the resulting stands. The poor quality of the stands is the result of a variety of factors, including poor species/provenance choice, inappropriate site preparation, poor management and other factors. Broadleaves are often established on open field sites, where exposure and other site factors may militate against the production of good quality broadleaves. Most broadleaf species do not naturally regenerate well in the open, so it is not surprising that they "struggle" following planting on open field sites. Although we have considerable experience in the growing of conifers, we are much less experienced in growing broadleaves. It is hoped that the new book on growing broadleaves in Ireland, entitled "Broadleaf Forestry in Ireland", to be published by COFORD late this year or early next year, will provide a comprehensive insight into the requirements necessary for the production of a valuable high quality broadleaf resource in Ireland. In addition, the results that are likely to emanate from the COFORD-funded B-SilvRD project (see Short and Hawe, this issue) will also help inform foresters and others, leading to improvements in broadleaf silviculture in Ireland. Nevertheless, insufficient attention has been given to a key driver in species-choice decisions – the grant and premium system.

The generally more attractive government grants and premiums offered for establishing broadleaves compared with conifers have contributed greatly to the shift in favour of broadleaves. Unfortunately, there is considerable anecdotal evidence that farmers and others who are establishing new forests have focussed too much on maximising grant and premium returns, leading to more inappropriate species selection than might otherwise occur. The grants and premiums need to be restructured to better reward good silvicultural practice, with the full amount being paid on merit only. A higher grant amount should be paid for the use of genetically improved material. Unfortunately, some of the "improved" material available for planting in the Irish market is of dubious quality, since much of this material has been developed for use in other countries and therefore, it is unlikely that the expected returns will be delivered under Irish conditions. For example, some of the improved Sitka spruce being sold in the Irish market is of QCI origin and is unlikely to perform any better than unimproved Washington origin material. The additional payments should be provided only for the use of improved material that has been approved by the Forest Service. The premium for broadleaves could be replaced by a lower basic premium, with additional amounts being paid when quality targets are met. This would require more inspections of broadleaf crops, perhaps at four-year intervals. The Forest Service may not have the manpower to carry out these inspections, so Forest-Service-approved assessors might be required to do this work. The need for other measures, such as the Forest Service Woodland Improvement Scheme and Reconstitution of Woodlands Scheme, might be greatly reduced if a scheme of this kind is implemented. If the forest owner is more acutely aware at the time of planting that he/she risks losing some of the premium if his/her stand does not perform well, better care may be taken during the establishment phase. Of course there is a risk that changes to the grant and premium scheme of this type might encourage the planting of more conifers in preference to broadleaves. However, this may be a preferable outcome if inappropriate species selections become less common and the quality of the broadleaved timber resource improves and becomes more consistent.

Another man who clearly aimed to improve silviculture in Ireland was Otto Reinhard. David O'Donoghue, in his article in Forest Perspectives, provides an absorbing account of pre-WWII life in Ireland as well as a fascinating picture of the machinations within the Forest Service. Contributions from Niall OCarroll and Donal Magner, with further extractives from the archives and recollections from several people who worked in forestry at the time, greatly augment this account.

The theme of broadleaves, and their place in the popular subconscious, is continued in the Trees, Woods and Literature and book review sections. Augustine Henry ("In the footsteps Augustine Henry") was a man who left a definite mark on Irish Forestry and was the first professor of forestry at UCD. With considerable foresight, Henry appears to have concluded that European methods of silviculture were sub-optimal for Irish conditions.

There are so many articles in this issue that it is impractical to comment on all papers, but it nonetheless demonstrates that scientific knowledge in forestry is expanding rapidly in Ireland. This bodes well for the development of sustainable forestry practices in Ireland, underpinned by solid scientific information.

Establishment of Ireland's projected reference level for Forest Management for the period 2013-2020 under Article 3.4 of the Kyoto Protocol

Kevin Black[a*], Eugene Hendrick[b], Gerhardt Gallagher[c] and Pat Farrington[d]

Abstract
There is increasing evidence that the extent to which managed forests can sequester carbon dioxide (CO_2) from the atmosphere is influenced by changes in forest area, age class structure and management practice. Signatory parties to the Kyoto Protocol can elect to account for CO_2 removals associated with Forest Management (confined to pre-1990 forest) under Article 3.4. A premise in formulating accounting rules under the Protocol was that forest sinks should be directly linked to direct human-induced activities. However, carbon (C) stock change in forests is also due to indirect human-induced activities. Indirect factors include increases in atmospheric CO_2 concentration, nitrogen deposition, and age class legacy effects resulting from historic forest management and afforestation activities. Current accounting frameworks attempt to factor out indirect human induced activities by setting a limit (cap) on accountable CO_2 removals or by setting a historic time series baseline (reference level), from which accountable annual removals/emissions can be derived. However, it is argued that these proxies do not factor out historic Forest Management effects (age-class legacies), which disincentivise parties from electing article 3.4 accounting. It is proposed that the use of a projected reference level, which considers age-class structure, can factor out dynamic age-class effects. Effects of indirect human induced activities are considered to be approximately the same in the projected reference level period and in the estimated period (i.e. the commitment period), and therefore they can be assumed to be factored out. However, election of Forest Management under article 3.4 using these newly proposed accounting rules requires development of national systems for forecasting future forest emissions and removals, as well as a methodology to characterise the effects of age class structure on the C balance of managed forests. In this paper, we outline methodologies used to derive a national C stock change reference level for Forest Management activity under Article 3.4 of the Kyoto Protocol for the period 1990 to 2020. We characterise the effects of age class and management legacy on C stock change over historic and projected time series. Different accounting frameworks are compared in relation to compliance with the Marrakesh Accords and ability to provide incentives to enhance sink capacity through Forest Management. We suggest that a projected reference level is best suited to accounting, factoring out legacy effects, and for providing an incentive framework to encourage additional mitigation activities under the Forest Management activity of Article 3.4 of the Kyoto Protocol. It is suggested that the projected reference level approach also factors out indirect human induced effects provided, that the same methodological approaches are used for both the projected reference level and the reported time series.

Keywords: *Forest carbon sinks, carbon accounting, age-class legacy.*

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Introduction

Ecosystem greenhouse gas (GHG) balance in temperate and boreal forests is largely influenced by forest management activities (Magnani et al. 2007). It is suggested that afforestation and changes in forest management have contributed to net C uptake (sink) in Northern Hemisphere forests (Ciais et al. 2008). In addition, relationships between forest productivity or net ecosystem uptake and stand age or management are well understood (Mund et al. 2002, Desai et al. 2005).

C sinks and emissions (sources) resulting from Forest Management (the activities specified in the Marrakech Accords and confined to forests in existence before 1990) were electable (on a voluntary basis) under Article 3.4 of the Kyoto Protocol for the period 2008-2012. Ireland and a number of other countries did not elect to report the activity, primarily due to lack of data and uncertainty regarding the implications of such a choice.

Accounting rules for Forest Management post 2012 are under negotiation in the United Nations Framework Convention on Climate Change (UNFCCC) process. A key issue is the establishment of a reference level of emissions/removals[1]. Other important issues include how to deal with large emissions resulting from fires, insect outbreaks and other disturbances, and the treatment of emissions from harvested wood products (Donlan et al., 2012).

The current (2008-2012) accounting rules were set out in the Marrakesh Accords in 2001 and the Kyoto protocol entered into in 2005. Adopted accounting rules were supposed to exclude indirect human-induced removals (sinks). These include the effects of elevated CO_2 levels, indirect nitrogen deposition and the dynamic effects of age structure resulting from activities and practices before the reference year (onset of the commitment period). Subsequent work by the International Panel on Climate Change (IPCC: Schimel and Manning 2003) concluded, however: "The scientific community cannot currently provide a practicable methodology that would factor out direct human-induced effects from indirect human-induced and natural effects for any broad range of land-use, land-use change and forestry (LULUCF) activities and circumstances." From an accounting perspective though, the rules governing Forest Management under Article 3.4 of the Kyoto Protocol for the first commitment period (2008-2012) cap[2] the amount of credits (for most Parties) on the basis of removing the effect of indirect human activities. This accounting rule was regarded as a proxy to direct human-induced change in forest C stocks.

The concept of projected reference levels (also known as a forward-looking baseline) was introduced to the negotiation process as a proposal to put in place an accounting system that did not reward BAU (business-as-usual activities- as can be the case in gross-net accounting[3]) and would be able to remove age-class legacy and other effects which could result in Parties incurring debits even though Forest Management would be a net sink in the period 2013-2020. The projected reference level also attempts to address other indirect effects, elevated CO_2 concentrations

[1] i.e. of GHGs to or from the atmosphere.
[2] A cap refers to an agreed limit of claimed C credits from forest management activities.
[3] See definition in next section.

(above pre-industrial levels), indirect nitrogen deposition, and the dynamic effects of age structure resulting from activities prior to 1st January 1990.

Implicit in the development of a projected reference level and in keeping up with UNFCCC GHG inventory and reporting processes, forest areas and emission factors should be complete, accurate, consistent, transparent and comparable across both historical (1990 to 2008) and projected time series (e.g. up to 2020). Furthermore, accounting for emissions/removals in future commitment periods should attempt to remove accountable age-class and related effects due to historic forest management practices or afforestation programmes prior to 1990 (legacy effects). Of course the selection of any specific historic reference level for Forest Management accounting will inevitably result in winners and losers (Böttcher et al. 2008), due to historic fluctuations in afforestation, felling and replanting rates (age class legacy) or changes in silvicultural policy such as rotation age or transition to continuous cover forestry (management legacy).

Calculating C stock change

The issuance of removal units (RMUs) for Forest Management under Article 3.4 is based on C stock change over time. A number of possible accounting methods are available, which express changes simply in the commitment period, or relative to a reference year or period. These are outlined below.

Gross-net accounting

This is the current accounting approach for Forest Management. No historic reference is applied; hence the gross stock change over the commitment period is used to calculate the potential level of credits or debits that will be issued for the activity during the commitment period. In this case the credit or debit over the first commitment period (C_{tc1}) is derived as (and see also Figure 1 as a guide):

$$C_{tc1} = \sum(C_{t1} ... C_{tn}) \tag{1}$$

where Ct_n is the forest C stock change for each year of the first commitment period.

Using the examples in Figure 1, application of the gross-net accounting rule would result in zero removal units (RMUs – credits) for the commitment period for scenario 1 (S_1, Figure 1). In the case of scenario 2 (S_2), trends in the managed forest C balance would result in an accountable debit, despite the fact that forests are a sink over the time series (t_0 to t_n). In contrast, scenario 3 (S_3) would result in credits (i.e. a gross removal or sink), even though the forest C balance changes from a sink to a source over the time series.

A cap on Forest Management was included for the first commitment period in order to reduce the scale of Forest Management relative to emission reductions. However, because the cap was a politically negotiated value (for a number of Parties) it was disproportionately large in some cases. For example, the allowable claimed credits, per unit area, for Japan would be far greater than those for Canada (see Böttcher et al. 2008). Another disadvantage of the gross-net method is that it does not account for natural or indirect human induced influences and legacy effects brought about due to activities, such as afforestation, often carried out several decades before the advent of the UNFCCC process.

Net-net accounting

This is the accounting approach used for cropland and grazing land management, and revegetation under Article 3.4:

$$C_{tc1}=\sum(C_{t1}...C_{tn})-(C_{to}\times N) \quad (2)$$

Where C_{t0} is the forest C stock in the reference year (usually 1990) and N is the length of the commitment period in years.

Schlamadinger et al. (2007) suggested that this approach include long-term trends in C emissions or removals and should allow the factoring out of indirect human induced and natural effects[4]. Therefore, C emissions and removals over the commitment period are assumed to be a function of many factors, including age class structure. Figure 1 illustrates hypothetical scenarios represented by different age class shifts (over time t_0 to t_1), starting at the same C stock change value in 1990. Scenario 1 (S_1) represents a constant, (most likely normally-distributed) age-class structure over time. For the period to t_o t_n, S_2 and S_3 represent left-shifting (old to young) and right-shifting (young to old) age class structures, respectively. To illustrate the projected reference level concept, additional sub-scenarios are applied to S_1 only, based on a business as usual (BAU) projected baseline (see arrow from S_1 to S_{1a}), for the second commitment period (t_{c2}). Two different hypothetical C stock change scenarios for tc2 are applied to represent a harvest level above (S_{1c}) or below (S_{1b}) the BAU scenario (S_{1a}).

Based on the examples shown in Figure 1, S_1 would result in zero accountable RMUs, S_2 in net credits (RMUs) and S_3 in accountable emissions. However, net–net accounting would result in some countries having a net debit even if the change over the commitment period resulted in C uptake (see S_3 in Figure 1). These trends may be related to a change from a negatively-skewed age-class distribution (old) to a positively skewed distribution (young), with a net debit ensuing in the commitment period where the forest C stock had increased more in the reference year than in the commitment period. On the other hand, credits would result for countries with a right-shifted age structure in which C gains are higher due an increase in age-related productivity (e.g. see t_0 to t_1 in S_2, Figure 1).

[4] Natural effects may include insect infestations or disease outbreaks etc.

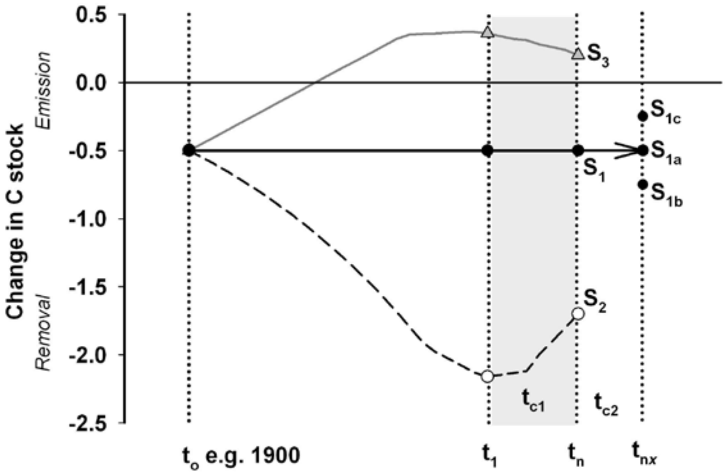

Figure 1: *Hypothetical forest management C stock changes for different scenarios (S_1, S_2 and S_3) over time: t_0 is reference level (for example 1990), t_1 is the start of the first commitment period (2008-2012), t_n is the end of the first commitment period, t_{nx} is the end of the second commitment period. Adapted from Böttcher et al. 2008. Refer to the text above for explanation of the different scenarios.*

<u>Projected reference level or forward looking baseline?</u>

An approach under negotiation in the UNFCCC LULUCF process (see latest version of draft text at http://unfccc.int/resource/docs/2011/awg16/eng/crp01.pdf [Accessed July 2012]) proposes to use a projected Forest Management reference level, based on net stock change in the period 2013-2020 using a BAU scenario. The approach is similar in some respects to net-net accounting but the reference (or bar) is a projected baseline (Figure 1, S_{1a}), which is compared to an *observed* C stock change over the same time period (Figure 1, S_{1b} or S_{1c}):

For example $S_{1b} \rightarrow C_{tc2} = \text{Obs. } C_{tn..nx} - \text{Proj.}Ctn_{.nx}$ (3)

where Obs. $C_{tn.nx}$ is the observed C stock change over the second commitment period (see S_{1b} in Figure 1);

$$\text{Obs. } C_{tn..nx} = \sum (S_1 C_{tn}, ..., S_{1b} C_{tn\,x}) \quad (4)$$

And where Proj.$C_{tn..nx}$ is the C stock change projected forward over the same period (S_{1a} in Figure 1):

$$\text{Proj.}C_{tn..nx} = \sum (S_1 C_{tn}, ..., S_{1a} C_{tn\,x}) \quad (5)$$

where C_{tc2} is the reference C stock change for scenario S_{1b} (see Figure 1).

This approach has the advantage of removing legacy effects, since they are included in the baseline and in the commitment period. Hence any deviation from the baseline is deemed to be directly attributable to a policy change, for example by increased or decreased levels of harvest compared with BAU. Using Figure 1 as an example, additional harvest over and above the BAU level would result in debits (see S_{1c}) and harvest below BAU would result in credits (S_{1b}). This approach provides a good basis for incentivising climate change mitigation activities in pre-1990 forests, but only where it can be transparently demonstrated that harvest differs from a predetermined BAU plan, and where forests are regenerated after harvest. Parties are required to justify that age class or management legacies influence current and projected C stock changes (see Appendix II of Decision 2/CMP.6 (FCCC/KP/CMP/2010/12/Add.1)).

The primary objectives of this study were to develop a method to estimate a consistent historical and projected time series, which is representative of Ireland's Forest Management activities under Article 3.4. We characterised changes in the age class distribution and management legacy of pre-1990 forests to investigate how these effects may have influenced historic and future (i.e. projected) national forest sinks. Currently proposed accounting methods are evaluated based on criteria for compliance with the Marrakesh Accords, but without dis-incentivising countries from election of these activities due to legacy effects. For example, it may be decided not to elect article 3.4 activities due to the introduction of management policies implemented a long time ago. Finally, we investigate the implications of electing Forest Management under the different accounting framework proposals.

Materials and methods

Compilation of historic age-class and forecast data

The pre-1990 Coillte estate was selected as a sample for the forest management areas since this accounted for 89% of the Article 3.4 forest in 2006 (NFI 2007). Afforestation records were obtained from the Forest Service (see Figure 2). Historic age class and forest area summary statistics from previous state and Coillte forest inventory records were obtained for 1959, 1968, 1979, 1986 and 1998 (See Table 1). The 2006 NFI sample plot co-ordinates were used as a random systematic sample points to select Coillte sub-compartments representing 35,533 ha or ca. 10% of the pre-1990 forest estate. Each sampled plot was scaled-up to the national level using the representative spatial sampling up-scaling factor of 400 ha[5]. The Coillte sub-compartment and management unit attribute data were obtained by GIS intersection with the point co-ordinates from the NFI permanent sample plots. This enabled a determination of a representative age-class distribution for the 2006 forest. The age-class distributions were projected forward to 2020 using the harvest forecast from the management unit plans.

Information on species composition, age, basal area, felling data and yield class,

[5] This is derived from the NFI sampling grid of 2 × 2 km, representing 400 ha.

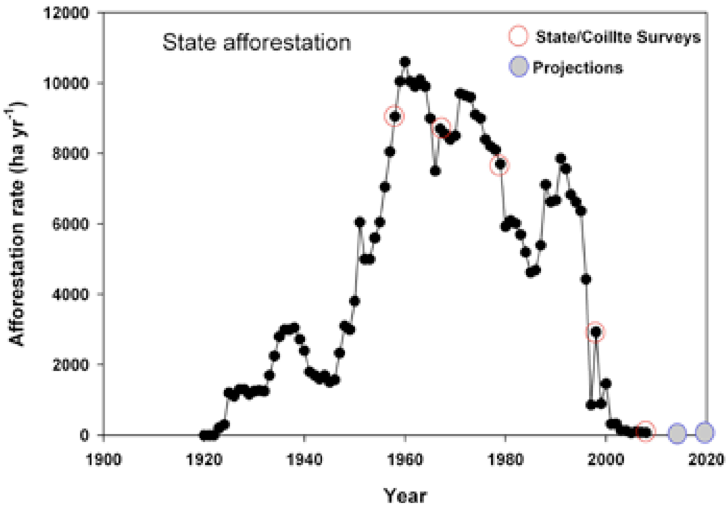

Figure 2: *Afforestation rates of state/Coillte forests since 1920 (Source: Forest Service) and survey years where age-class distribution analysis was performed based on historic and projected data sources.*

obtained from the Coillte sub-compartment and management records, was also used to estimate projected emissions/removals for Article 3.4 forest. The projected timber forecasts for the period 2010 to 2020 were obtained from the Coillte timber supply forecast (Anon. 2008). The harvest forecast from 2015 to 2020 (Coillte smoothes the harvest forecast to deliver a comparable year-on-year harvest and roundwood supply) was smoothed using linear interpolation.

Replanting of clearfelled areas was assumed to take place two years after harvest. We assumed all clearfelled forest areas were replanted (to comply with national forest legislation), unless management plans indicated a planned permanent deforestation event.

Characterisation of age class distributions

No raw data for the historic datasets were available. Therefore, the frequency distributions for historic data were generated from age-class histograms with a 10-year bin class using a Gaussian, three parameter non-linear model (see Figure 2, SigmaPlot v7.0, SPS Inc, USA). The same procedure was repeated for the 2006 sample and projected data for comparison purposes.

We used Gini coefficients and Lorenz curves because this is a measure of inequality of distribution of age classes (Sadras and Bongiovanni 2004). The Lorenz curve was developed in economic science as a wealth index, where a cumulative proportion of the population is plotted against a cumulative proportion of wealth. It is commonly standardised so that each axis ranges between 0 and 1 and represents the degree of inequality in the distribution of wealth or income in society. In this case, the Lorenz curve was used as a measure of inequality of the age classes in pre-1990 forest.

Use of the Gini coefficient (G) is preferred in plant science applications because of its relative robustness to slight changes in the right tail of plant size distribution data (Hay et al. 1990):

$$G = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} |x_i - x_j|}{2\bar{x}n(\bar{n}-1)} \tag{6}$$

where x_i is the age of the i^{th} sub-compartment in the sampled population, x_j is the mean population age, and n is the population density. Gini coefficients are a numerical representation of the Lorenz curve and range from 0 to 1, with a value of 0 depicting an evenly-distributed age-class frequency.

Adjustments for age class legacy

Following the estimation of historical trends, two approaches were adopted to make adjustments of age class legacy:

a) Historical time series adjustment.

This was achieved by applying the mean growth increment before harvest (GrossΔB) from the projected second commitment period to the baseline data, where the age class distributions were different. This was then weighted, based on the G coefficient and mean age class ratio, as shown in equation 7:

$$Gross\Delta r_{(ref)} = A \times meanGI_{(proj)} \times \left[\left(\frac{Gcoeff_{(proj)}}{Gcoeff_{(ref)}} \right) \div \left(\frac{meanAge_{(ref)}}{meanAge_{(prog)}} \right) \right] \tag{7}$$

where GrossΔB is the adjusted reference year gross biomass increment before harvest (t C yr^{-1}), A is the total forest area (ha) in the reference year, meanGI is the mean biomass increment before harvest for the projected years (i.e. 2.4 t C ha^{-1} yr^{-1}), Gcoeff is the G coefficient for the reference and projected years and, meanAge is the mean stand age in the reference and projected years.

b) A forward-looking baseline.

Using the approach of Böttcher et al. (2008), the Coillte harvest forecast was used to estimate the BAU baseline scenario (see Introduction, Figure 1).

Estimation of historic and projected emission/reduction trends

The evolution of CARBWARE

The Irish C reporting system (CARBWARE v4.5), described by Gallagher et al. (2004) was initially implemented to meet reporting requirements to the UNFCCC on national forestland remaining forestland (F-F) and land converted to forestland (F-L). To facilitate the 20-year transition between F-L and F-F, CARBWARE v4.5 was specifically designed to generate a time-series estimate going back to 1970, using species distribution activity data for young (7-25 year-old) and mature stands (>25 years; see Gallagher et al. 2004). The early version of CARBWARE was, however, a static model (it had two age classes only) representing C dynamics for two forest-type cohorts (conifers, based on Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and broadleaves, based on beech (*Fagus sylvatica* L.) - see Gallagher et al. 2004). In addition, the old model only considered C stock changes in the living biomass and litter pools, and assumed deadwood C stock changes were in steady state. The original model is still used, in combination with a newer version of CARBWARE, to form a hybrid model, because it is able to extend C stock change estimates back to 1970. This forms the basis for historic data estimates for both UNFCCC and Kyoto Protocol Article 3.4 forests (Figure 3).

To facilitate Article 3.3 reporting requirements, CARBWARE has evolved from a Tier 2 to a Tier 3 (most specific and country-based reporting tier[6]) system, using forest inventory data, yield models and national research information (see Black and Farrell 2006, Black et al. 2009a, Gallagher et al. 2004). The outputs from the model are used to generate historical and projected data for activities relating to Articles 3.3 and projected data for Article 3.4 of the Kyoto Protocol from 2008 onwards.

<u>The hybrid CARBWARE model</u>

The historic emissions/removals for forestland remaining forestland and land converted to forest (i.e. the Convention reporting format, see i. in Figure 3) were calculated using a hybrid model based on CARBWARE v4.5 (described above) and the newer dynamic model (CARBWARE v5).

The initial estimates for Article 3.4 forests (Figure 3; box *iii. Pre-1990 (3.4)$_{estimated}$*) were calculated based on the difference between the sum of all forestland in the UNFCCC data (dark green box *i. Total*) minus the Article 3.3 emission/removal (ii. Post-1990 (3.3)) for the entire time series 1990-2020. To reduce the potential for over- or under-estimation bias in the data due to the use of different models in the projections, the historic Article 3.4 data were calibrated and adjusted using back-extrapolation, based on the relationship between the projected Article 3.4 data (dark green box *iv. Pre-1990 (3.4)$_{projected}$*) and the UNFCCC derived data (dark green box *iii. Pre-1990 (3.4)$_{estimated}$*). The approach adopted to calculate Article 3.4 projected data (dark green box *iv. Pre-1990 (3.4)$_{projected}$*) was based on CARBWARE v5, using activity data derived from the intersected NFI and Coillte sub-compartment data (as used to derive the age class distribution for 2006 onwards).

The emissions/removals for *F-F* and *F-L* categories (Figure 3) were simulated using the original methodology as described in previous national submissions to the UNFCCC – "Convention submissions" (CARBWARE v4.5; see Gallagher et al. 2004, McGettigan et al. 2006) with the following modifications:

1. All areas afforested and replanted since 1990 were excluded from the model; C stock changes were estimated using CARBWARE v5.
2. Soil stock changes were assumed to be at steady state by 20 years, following a land use transition into forest.
3. Soil and deadwood stocks were also assumed to be at a steady state in forestland remaining as forestland. This is consistent with the 20-year transition and

[6] Tiers refer to methodological rankings used as set out by the IPCC good practice guidance. Tier 1 refers to default methods, higher tiers use country-specific and increasingly more complex modelling approaches.

default values recommended in the IPCC 2006 Good Practice Guidance.

4. Mean accretion rate, which reallocates areas representing young forest into the old forest cohorts after 25 years, was replaced by actual areas. This was carried out to ensure that the there was no accretion of the Forest Inventory and Planning System (FIPS) data from 2014 onwards (i.e. 1989 was the last afforested and replanted area cohort moved to the old forest cohort). This meant that the pre-1990 forest C stock in old forests (>25 years) decreased from 2014, due to felling and no addition of new stocks due to replanting and reforestation. Similarly, C stocks of the new forest cohort (7-25 years old) were zero from 2006 onwards.

CARBWARE v5

Estimates of changes in biomass over time were based on the new CARBWARE v5, using forest growth models and research information from current and past COFORD-funded projects (Black and Farrell 2006, Black 2008, Wellock et al. 2011). A common approach that is used to report regional annual C stock changes or interpolate between inventory measurements involves mass-balance ($NEP_{\Delta C}$) estimates. This is normally based on models/measurements which describe the changes in biomass (ΔC_b), litter (ΔC_{litter}), dead wood ($\Delta C_{dead\ wood}$) and soil (ΔC_{soil}) C pools:

$$NEP_{\Delta C} = \Delta C_b + \Delta C_{litter} + \Delta C_{dead\ wood} + \Delta C_{soil} \tag{8}$$

Stand biomass

The dynamic CARBWARE v5 growth model describes changes in ΔC_b based on tree-level allometric functions (for example diameter at breast height (DBH) and top height) and stand attributes (stocking) for representative species, according to Forestry Commission yield models (Edwards and Christy 1981, Black and Farrell 2006). For this exercise, stand attributes, such as age, mean DBH, top height, stocking and timber harvested, for six species cohorts (spruce, fir, larch, pine, slow growing and fast growing broadleaves), were used as inputs for the calculation of cumulative stand biomass using species-specific allometric relationships (Black et al. 2004, Black et al. 2007, Tobin et al. 2006, Black and Farrell 2006).

A modified expo-linear growth function (Monteith 2000) was used to more accurately simulate growth (DBH and height) during the early years of the rotation and interpolate growth over time, since neither the dynamic or static models consider growth of young forest (<10 years-old).

Stand biomass (St) was expressed as:

$$St = Mt \left[\frac{1 - e^{-k_s (k_t - t)}}{1 - e^{-k_s k_t t}} \right] \tag{9}$$

where:

$$Mt = \frac{Cm}{Rm} \ln\left[1 + \frac{Co}{Cm} e^{Rmt} \right] \tag{10}$$

Mt is Monteith's function, Cm is maximum growth rate, Co is initial absolute growth rate and Rm is the initial relative growth rate and t is time (years). Parameters Cm, Rm, Co, k_s and k_t were fitted using the least squares optimisation method to estimated stand biomass values.

The current annual increment (ΔC_b) for any given year was then calculated as:

$$\Delta C_b = St_{n+1} - St_n \tag{11}$$

The same approach was used to calculate aboveground and belowground biomass changes.

CARBWARE v5 simulates the C stock changes in un-thinned stands modified from Forestry Commission stand-level models (Edwards and Christy 1981). Stand-level volumes removed due to proposed thinnings were not indicated in the Coillte management plan forecasts. In the Coillte forecast, thinning volumes were aggregated to national level. For the bottom-up stand level projection of thinned stands, we assumed that thinning occurred at marginal thinning intensity using thinning volumes based on static yield tables (see Edwards and Christy 1981). Stands were clearfelled when indicated in the forecast management unit and sub-compartment level plans. A timber (minimum top diameter of >7 cm) harvest extraction efficiency of 96% was assumed for all harvest activities. The CARBWARE v5 model outputs for volume removed at harvest were compared with the forecasted (2001 to 2015) timber volumes (Gallagher and O'Carroll 2001) and the Coillte forecast data (2008 to 2020) for model optimisation.

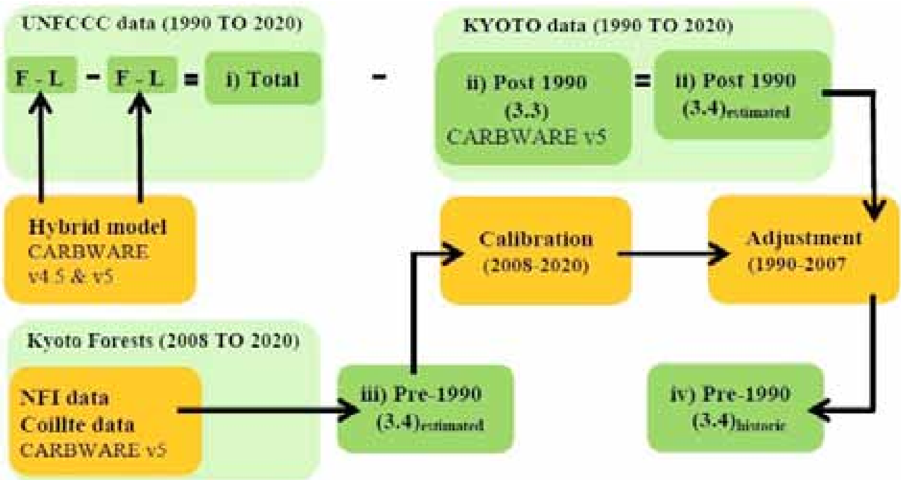

Figure 3: *The overall modelling approach for Article 3.4 forests showing the methodology used to generate the historic and projected time series. Refer to text for a detailed explanation of the approach.*

Other C pools

The biomass model also simulates the changes in other C pools, such as litter, and deadwood for different species and management scenarios, based on research information (Black et al. 2004, 2007, 2009a, Tobin et al. 2006, 2007, Saiz et al. 2007). Annual litter gains and losses ($\Delta C_{litter} = C_{1gain} - C_{1loss}$) were calculated based on foliar biomass functions, litter-fall models (Tobin et al. 2006), estimates of harvest residue and decomposition factors:

$$C_{lgain} = (FB \times Ft) + Br \tag{12}$$

where FB is foliage biomass (t C ha^{-1}), Ft is leaf or needle turnover rate (Ft = 0.2 (i.e. 5 years) for evergreen conifers (Tobin et al. 2006) and Ft = 1 for deciduous species). Br is brash (harvest residue in the form of branches, needles and tree tops) added to the litter floor.

Brash (Br < 7 cm diameter) was calculated as:

$$Br = AG_{harvest} - Tm_{harvest} \tag{13}$$

where AG is total biomass – belowground biomass and Tm is timber cut at harvest (for trees whose DBH >7 cm, t C ha^{-1}).

Emissions from the accumulated litter pool (ΔC_{lloss}) for any given year (n) were calculated as a function of litter turnover rates (Lt) based on experimental data (Lt = 0.14; Saiz et al. 2007) :

$$C_{lloss_{(n+n)}} = \sum \left[\left(C_{lgian_{(n)}} \times Lt\right), \left(C_{lgain_{(n)}} \times (1 - Lt)\right) + C_{lgain_{(n+n)}} \times Lt \right] \tag{14}$$

The dead coarse wood C pool ($C_{dead\ wood}$) includes C gains ($C_{d.gain}$) and decomposition losses ($C_{d.loss}$):

$$C_{d.gain} = st + hr + tr + mort \tag{15}$$

where mort is mortality (as specified in both the static yield tables and dynamic yield models), st and hr represent stumps and roots of harvested trees (total biomass harvest - $AG_{harvest}$) and tr is the harvest residue of remaining wood on site after harvest (assumed to be 4% of the biomass from the $Tm_{harvest}$ pool).

The clearfell harvest residue losses were also applied to sub-compartments clearfelled since 2000 to account for the historic deadwood and litter decomposition losses in the model. The CARBWARE v5 model assumes that all timber C is lost at harvest and does not account for C residence time in harvested wood products (HWP). This is in line with the current KP accounting rules. The treatment of HWP in the construction of the forest management reference level is discussed by Donlan et al. (2012).

Results and Discussion

Calibration of the hybrid model

Generally there was good agreement between the hybrid model and previously submitted UNFCCC data, particularly for the periods 2001 to 2007. There was a somewhat higher emission pre 2012 in the new projections, reflecting the growth patterns of younger forest, where the growth increment may be lower than the mean increment of 7 m^3 ha^{-1} yr^{-1} assumed by Gallagher et al. (2004).

There may be a slight modelling bias in the projections due to inconsistencies in the time series, brought about by treating younger and modelled forest separately in the hybrid model. This was addressed by calibration with CARBWARE v5 and adjustment of the historic data to produce a consistent time series (Figure 3). This back-extrapolation adjustment is in accordance with prescribed procedures for national adjustments and compliance under Articles 5 and 7 of the Kyoto Protocol. There were no historic activity data available for use in the CARBWARE v5 model.

Age-class legacy effects

It is important to point out that Ireland's forest cover at the beginning of the 20th century had declined to 1.5% of the land area (OCarroll 2004). Afforestation programmes since that time have increased the forest area to just over 10% (NFI 2007). There was a rapid expansion in the state forest area after 1945 (Figure 2). This resulted in the afforestation of ca. 150,000 ha from 1948 to 1968. The mean age of the State/Coillte forests (afforested before 1990) increased from 13 years in 1959 to 28 years in 1998, followed by a slight decline to 22 years by 2006 (Table 1).

Table 1: *Summary of the areas sampled and source data for the age-class distribution analysis.*

Year	Area sampled (ha)	Mean age[a] (years)	Source	Comment
1959	55,226	13	O'Muirgheasa 1964	Afforested areas since 1948 added to data to include 1-10 year-old crops
1968	186,107	15	O'Flanagan 1973	Afforestation areas since 1959 included (as above)
1979	280,800	18	Anon. 1980	
1986	Data missing			
1998	315,967	28	Coillte records	Afforested areas since 1990 removed from data
2006	35,553	24	NFI/Coillte	
2012	35,553	22	NFI/Coillte	Projection based on forecast and management plans
2020	35,553	25	NFI/Coillte	As above

[a] Mean forest age was based on reconstructed age-class distributions using a Gaussian function (see Figure 4).

Figure 4 shows the age-distribution histograms over the time series. Based on these data, it is evident that there was a "right-shift" in the age-class distribution from a positively-skewed (young) age-class distribution in 1959 to a near normal distribution in 1998. However, there was a reversal (left-shift) towards the younger age classes by 2006. This trend continues up to 2012, followed by a right-shift towards older age classes in the projected 2020 time series. These age-class distribution shifts are consistent with historic afforestation rates and a mean clearfell age of ca. 42 years (i.e. commercial rotation of 20% less than the age at maximum mean annual volume increment of Sitka spruce, yield class 16 m^3 ha^{-1} yr^1, see Table 2) in place from the 1990s.

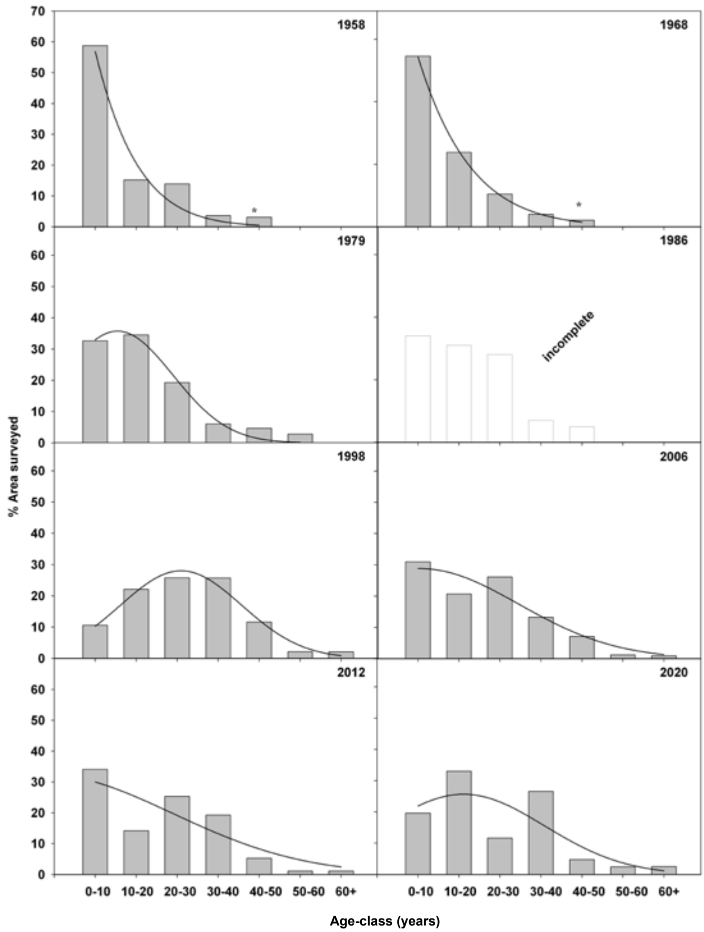

Figure 4: *Pre-1990 forest age class frequency distributions based on summary statistics (grey histograms) and a fitted distribution curve (solid line) using a Gaussian function. The 1959 and 1968 data (see Mean Age in Table 1) did not categorise age-classes older than 50 years.*

Characterisation of the age class distributions using the Gini coefficient (G) and Lorenz curve provide a measure of changes in the age-class distribution over time (Figure 4). A forest with equal areas in each age-class will have a G value of zero and a straight line for the Lorenz curve (Figure 5). This uniform age-class distribution can be visualised as a histogram with the same value for each age-class frequency bin. The lower G value and smaller area of the Lorenz curve under the theoretical uniform age distribution line, shown for 1998 in Figure 5, suggest a more uniform age-class distribution when compared with 1968 and 2006.

An important consideration when using G coefficients is that different Lorenz curves can produce similar G values. Therefore, it is important to consider both the G value and mean age-class when considering a nationally-specific reference period for accounting sinks in the future.

The observed decline in gross biomass increment between 1998 and 2020 (Table 2) may be due age-class and/or management legacies. The age-class legacy effect is manifested by the change in the mean age and age-class frequency (as shown in Table 2) and a decline in productivity in younger crops after clearfell. However, a decline in biomass increment may also be associated with premature clearfelling due to a reduction in rotation age (i.e. management legacy, Table 3).

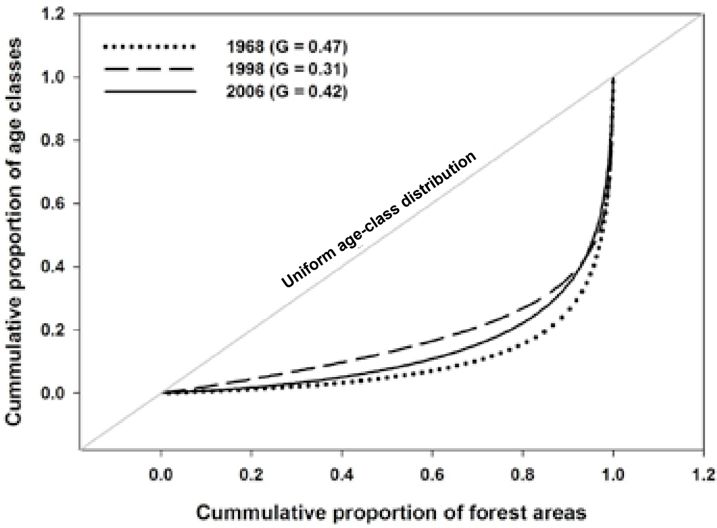

Figure 5: *The Lorenz curve as applied to age-class inequalities across the re-sampled age-class populations for 1968, 1998 and 2006.*

Table 2: *Mean age-class and G values over the pre-1990 forest time series and the potential influence of age-class legacy on biomass productivity.*

Year	Mean age[a] (years)	G coefficient	Gross biomass increment[b] (t C ha^{-1} yr^{-1})
1959	13	0.53	n.d.
1968	15	0.47	n.d.
1979	18	0.43	n.d.
1986	*Missing data*	*Missing data*	*Missing data*
1998	28	0.31	2.9
2006	24	0.42	2.7
2012	22	0.43	2.4
2020	25	0.40	2.4

[a] Mean forest age based on reconstructed age-class distributions using a Gaussian function (see Figure 4).

[b] Gross biomass increment (i.e. biomass increment before harvest removal) was taken from the CARBWARE model outputs based on the total gross biomass increment and representative pre-1990 forest areas.

Management legacy effects

From a productivity perspective, maximum merchantable volume productivity over time is achieved by final harvesting at the age of maximum mean annual volume increment (MMAI). There is evidence of a pre-mature rotation age (i.e. clearfell before MMAI is reached) in the pre-1990 estate (Table 3). This is consistent with the introduction of new harvesting policy in the 1980s following economic analysis undertaken by the Crop Structure Section of the Forest and Wildlife Service Research Branch in 1976 (Henry Phillips, pers. comm.)[7]. Clearfell scheduling is currently based on a commercial rotation age, which is the age at MMAI minus 20% for Sitka spruce, and 30% for Norway spruce and lodgepole pine (Table 3). These species account for over 95% of harvest in pre-1990 forests.

[7] Based on an economic analysis undertaken in 1976-77 by the Crop Structure Section of the Research Branch of the Forest and Wildlife Service, which resulted in the Forest and Wildlife Service issuing an Operational Directive on *Rotation Lengths and Thinning Regimes for Conifers*.

Table 3: *Mean rotation ages of different species from the forecasted sub-compartment and management unit data for the period 2008 to 2020. (Abbreviations: n is the number of compartments, MMAI the maximum mean annual commercial volume increment, n/a not applicable).*

Species		Age (years)		
		-at Forecast rotation	-at commercial rotation	-at MMAI
Lodgepole pine (n = 53)				
	mean	39	40	57
	range	30-86	32-52	45-75
Sitka spruce (n = 156)				
	mean	41	42	52
	range	11-73	33-52	42-65
Norway spruce (n = 17)				
	mean	40	36	51
	range	12-50	31-40	45-57
Other conifers (n = 18)				
	mean	48	n/a	59
	range	10-48		42-75

Harvested volumes from prematurely clearfelled stands represented ca. 30% of the annual harvest in pre-1990 forests between 2000 and 2005. This reduced to ca. 10% for the years 2007 and 2008. However, analysis of projected clearfell data, based on sub-compartment and management unit records, suggest that premature clearfell will account for ca. 35% of the sub-compartments harvested in pre-1990 forests over the period 2008 to 2020.

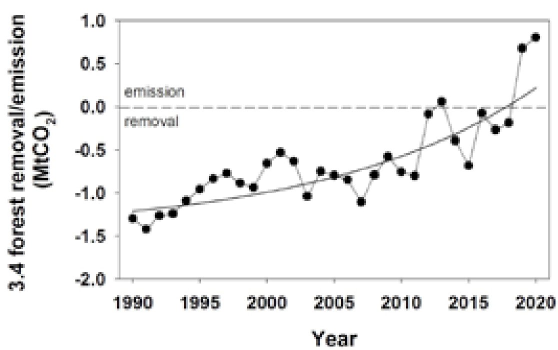

Figure 6: *The total C stock change, excluding harvested wood product storage for all pre-1990 forests (Article 3.4), for the years 1990 to 2020. The solid regression line is included to indicate smoothed trends over time.*

Historic and projected emission/removal for Article 3.4 forests
The historic and projected emission/removal estimates, under current accounting rules (assuming HWP stock change is instantaneous) for the pre-1990 forest, show a marked decline in removals, particularly since ca. 2000 (Figure 6). The pre-1990 forest changes from a net sink of 1.2 Mt CO_2 in 1990 to a net emission of 0.8 Mt CO_2 by 2020.

Analysis of the different C pools suggest the net C stock changes (Figure 6) are primarily associated with age class and management legacy effects (Tables 2 and 3). This is manifested by changes in:

1. an increased harvest with a concomitant decrease in the net biomass increment and
2. a decrease in the deadwood sink (Figure 7).

a) Increment versus harvest
The slight decline in biomass increment net of harvest over the time series is primarily associated with an increase in harvest from pre-1990 forests. The CARBWARE v5 model and the Coillte timber forecast shows that the equivalent harvest from pre-1990 forests increased from 1.6 M m^3 in 1990 to 3.1 M m^3 in 2020 (Anon 2008, Donlan et al. 2012). The smoothed harvest from pre-1990 forests is projected to be 3.1 M m^3 by 2020.

The roundwood harvest per unit of productive forest in pre-1990 forests has increased over the past 20 years. For example, the harvest volume in Article 3.4 forests in 1990 was ca. 1.4 M m^3 from a productive area of 466 kilo-hectares (kha; which includes open areas) compared with a projected harvest of 3.1 M m^3 from an area of 452 kha in 2020. This represents an increased mean harvest from the total productive area from 3.0 m^3 ha^{-1} in 1990, to 6.8 m^3 ha^{-1} in 2020. However, when expressed on the basis of harvested area, the harvest per unit of clearfell would be similar over the time series (ca. 350 m^3 ha^{-1}). This is consistent with the increase in the area of forest replanted following harvest in the Coillte estate, from ca. 4,000 ha in 1990 to 8,000 ha in 2007 (under Irish forest legislation all clearfelled areas must be replanted).

The decline in biomass increment net of harvest (Figure 7) may also be associated with a small decline in gross biomass increment (i.e. before harvest), but to a lesser extent (see Table 2).

b) The deadwood pool harvest residue effect
The decrease in deadwood C stock removals (Figure 7) may be associated with both the age class/management legacy and harvest residue decomposition effects. Figure 8 shows the model output for the net C stock change (including biomass, litter and deadwood pools) of a typical forest type (Sitka spruce, yield class 16 m^3 ha^{-1} yr^{-1}). Symbols with positive values represent losses (or emissions of C) due to harvest as thinnings (T1 and T2), clearfell (CF) and residual decomposition losses associated with harvest residue (HR). Note that the residual C loss of HR following first rotation is due to the decomposition of deadwood, roots and litter. This C loss is carried over to the second rotation for a period of ca. 30 years. The C gains from biomass increment in the second rotation are included in the C budget and there is a net C loss for the first

10 years of the second rotation (Figure 8B).

The carry-over of harvest residue decomposition losses has important implications for the legacy effects in setting a national reference level. This is particularly relevant when there are historical fluctuations in the areas being clearfelled, as is evident from the Coillte replanting records. The replanting records for the Coillte estate show an increase in areas replanted up to 2000, followed by a projected downward trend into the 2012 to 2020 period. For this study it was assumed that the replanting rate mirrored the clearfell trend.

Factoring out legacy and indirect human induced effects

Böttcher et al. (2008) advocate the use of a projected Forest Management reference level to factor out age-class and other management-legacy effects. A possible problem with the concept is that indirect human induced and natural activities are not always excluded from accounting, depending on the models and methodologies included. This is, however, not an issue if the same modelling framework and assumptions (for example, a model such as CARBWARE) are used for both the projected reference level and the reported time series. If different methods are to be used, this may necessitate a technical correction (which is provided for in the current LULUCF negotiation text) to ensure time series consistency. In such cases it may be necessary to factor out indirect human-induced activities, which is difficult unless projection models include functionality for the characterisation of CO_2 fertilisation and N deposition. Few, if any, countries reporting to the UNFCCC have developed models which factor out indirect human induced activities. For example, CARBWARE is an empirical model with no process based functionality to include the effects of climate change or N deposition. Therefore, if a projected Forest Management reference level is compared with observed stock change in the projection period series (which presumably includes indirect and natural effects), there would be no factoring out of natural or indirect

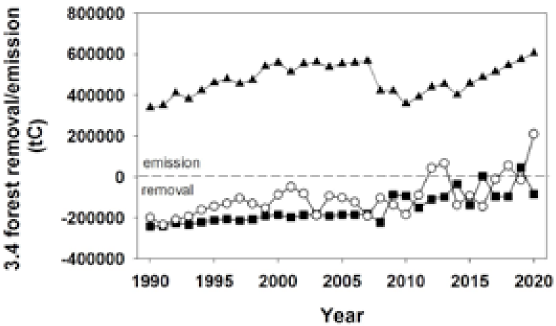

Figure 7: *C stock change of major C pools in pre-1990 (Article 3.4) forest over the years 1990 to 2020. Values represent the flux of the C pools for harvested roundwood (closed triangles, all of which is assumed to be immediately oxidised under current accounting rules), net biomass increment after harvest (open circles) and the deadwood pool (closed squares).*

human-induced activities. This highlights the importance of a provision to allow for a technical correction in order to ensure time-series consistency and that indirect human-induced emissions/removals are factored out for both the reference level and reported time series. Overall, factoring out indirect human induced and natural effects remains a scientific challenge because interactive effects, feedback mechanisms and scaling such effects to the regional level are still poorly characterised (Ainsworth and Long 2005).

Historical adjustment – an approach to deal with age-class legacy
During the period when options to deal with the age-class legacy effect were being discussed in the UNFCCC negotiations, the feasibility of a backward adjustment of the historic time series was explored, so that age-class legacy effects were accounted

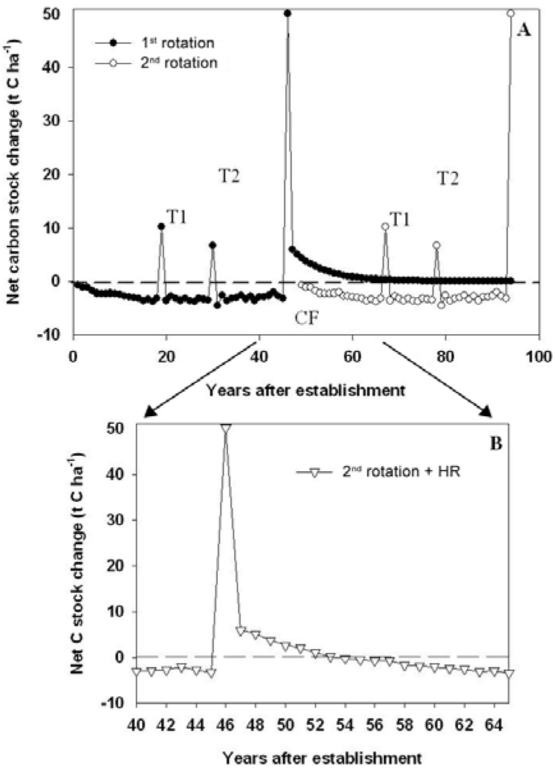

Figure 8: *Estimated net C stock change of a yield class 16 Sitka spruce stand over two rotations (**A**) and the combined effect of harvest residue (HR) decomposition from the first rotation and biomass growth in the second rotation, due to replanting after two years (**B**). T1 and T2 represent thinnings and CF indicates clearfell at maximum mean annual increment (rotation age of maximum roundwood productivity). Positive values represent a loss (emission) of C due to harvest and harvest residue decomposition (HR).*

for, while still fulfilling the criteria set out by the Marrakesh Accords. The advantage of this method is that the traditional net-net accounting methods can then be used for all land-use classes, which should in theory, also exclude indirect human induced and natural effects (see Introduction). The approach aimed at adjusting the historical reference-period values, based on a mean growth increment (before harvest) over the projected time series.

For those years where no age class data were available to derive G coefficients, a linear decline in the coefficient from 0.42 in 2006 to 0.303 in 1998 was assumed (i.e. a decline of 0.013 units per year). Similarly, the mean stand age was assumed to decline by 0.5 years per year between 2006 and 1998. This weighted adjustment, in theory, would only adjust for the relative difference in mean age and age-class distribution, assuming a linear relationship between these variables and mean GI. This historic adjustment approach (Eq. 15, Figure 9) is, however, based on the assumption that only age-class legacy is influencing the increment before harvest, which is not correct since it has been shown that part of the reduction in increment before harvest is also due to premature clearfell (i.e. management legacy). This approach is further limited by the lack of historic age-class data for the entire time series.

<u>Projected Forest Management reference level or forward looking baseline</u>
The projected reference level (referred to as the forward-looking baseline) assumes that the Coillte forecast represents a BAU scenario (see Introduction). Using this approach, the reference level for the second commitment period (2013 to 2020) would be -0.008 M t of CO_2eq[8] per annum (derived from the mean of the projected C stock change from 2013 to 2020 shown in Figure 6). This includes an estimated annual emission of 0.012 M t of CO_2eq from wild fires, which was obtained from the mean annual emission from fires since 1990.

The advantage of this accounting approach is that it provides an incentive/ disincentive to undertake activities that increase or decrease either CO_2 sequestration potential or stock change due to varying harvest levels relative to BAU. A disadvantage is that the use of projected data leads to a larger level of uncertainty when compared with historic data. To address this and other issues, the current draft negotiation text includes a proposal to have an asymmetrical cap which would limit credits and debits under this Article to fixed percentages of 1990 emissions.

Implication of different accounting approaches
The implications of proposed Forest Management accounting approaches (Table 4) for the period post-2012 are summarised below:

1. Gross net accounting using a discount rate.
   Although forest management has been capped for CP1 (2008-2012), it is likely that a gross-net approach would be based on a discount (85% was used in the forest commitment period) of net removals (or emissions). This accounting

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[8] CO_2 equivalents (eq) include the global warming potential of other gases such as methane (24 times that of CO_2) and nitrous oxide (298 times that of CO_2) all expressed as equivalents of CO_2. Wild fires could result in an emission of both methane and nitrous oxide, in addition to CO_2.

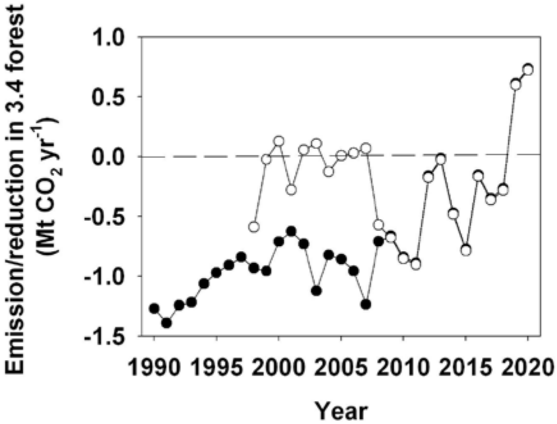

Figure 9: *Historic and projected C stock change in pre-1990 forests (closed circle symbols as shown in Figure 6) and historically adjusted reference period (open circle symbols, see Eq. 7) for the years 1990 to 2020. Note: the adjusted reference time series could only be calculated from 1998 due to missing age class distribution data (see Figure 3 and Table 2).*

framework essentially provides credits for BAU in pre-1990 forests, and when combined with a cap, provides little incentive for climate change mitigation activities in pre-1990 forests that go beyond BAU.

2. Net-net accounting using reference periods 1990-1994 and 2000-2004. The proposed use of a reference level based on a historic period rather than a specific year is intended to counteract inter-annual variability in C stock changes.
3. Net-net accounting with an adjusted reference level from 2000-2004, shown in Figure 9.
4. A projected reference level for the period 2013 to 2020 with a 5% cap on credits and a 10% cap on debits should be adopted.
5. The reference value over the commitment period is calculated using the mean annual C stock change for the reference periods, multiplied by the number of years in the commitment period (assumed to be 8 years, 2013-2020). The potential debit or credit is based on equations 1, 2 and 3 (see Introduction) and excludes RMUs from HWP.

Table 4: *The implications of different Forest Management accounting approaches under Article 3.4, based on historic (unadjusted or adjusted) and projected C stock change trends.*

Reference period	Ref level	Ref level over period 2013-2020	Credits/debit over period
	($Mt\ CO_2\ yr^{-1}$)	($Mt\ CO_2$)	($Mt\ CO_2$[a])
1. Gross-net with an 85% discount[b]			
n.a.	n.a.	n.a.	-0.001
2. Net-net un-adjusted historical time series[c]			
1990-1994	-1.222	-9.776	9.712 (no limit)
2000-2005	-0.776	-6.208	6.144 (no limit)
3. Net-net with weighted adjustment for legacy[c,d]			
1990-1995	n.d.	n.d.	n.d.
2000-2005	-0.022	-0.176	-0.406 (no limit)
4. Forward looking baseline with asymmetrical cap[e]			
2013-2020	-0.008	-0.064	0 (-22.08 to 44.24)

[a] Positive values represent an emission or debit, negative values represent a removal or credit.
[b] Gross-net accounting does not have a reference level (n.a.: not applicable).
[c] Net-net accounting does not normally have a debit or credit cap; therefore there are no limits on potential credits or debits.
[d] There are no data available for a historical adjustment prior to 1998, so the 1990-1994 reference level could not be determined.
[e] The caps are applied as 5% of base year emissions (excluding LULUCF) for credits and 10% for debits (base-year emissions in 1990 were 55.374 Mt CO_2eq excluding LULUCF).

Conclusions and practical implications

Based on the scenario analysis presented in Table 4, it is evident that gross-net accounting with an 85% discount offers little incentive for Ireland to elect Forest Management post-2012. We have also demonstrated that the currently used net-net accounting framework could result in significantly less ambitious targets being set when taking LULUCF into account (debits of 6.1 to 9.7 M t CO_2) over the period 2013-2020. This is clearly related to age-class and management legacy effects from the pre-1990 forest, which affect the current and projected C stock changes (Tables 2 and 3, Figure 6). This should be taken into account in future accounting frameworks.

Factoring-out age class legacy can be done in several ways. The historical adjustment we examined, when combined with net-net accounting, does offer some advantages, but only addresses age-class structure. The option, which is the most effective in removing both the age-class and management-legacy effect, is a projected reference level, based on BAU management policy. Differences between the BAU projections and future C stock change would, therefore, reflect accountable credits or debits arising from additional activities in pre-1990 forests. The inclusion of an asymmetric cap at the proposed levels (5 and 10% of 1990 emissions) provides an incentive for enhanced sequestration through forest management, but also reduces large emission debit risks. For example, accounting using a projected reference level, with an asymmetric cap would allow a national credit in pre-1990 forest of up to 22.08

Mt CO_2 over the period 2013-2020, but at the same time limit potential debits to 44.24 Mt CO_2.

The use of a projected reference level also has the potential advantage of providing the same or a similar incentive basis for all Parties that choose to account for Forest Management in the future.

Factoring out of indirect human induced effects related to elevated CO_2 levels and nitrogen deposition is only addressed (in the formulation of the cap on Forest Management) under the accounting framework for the first commitment period. The proposed projected reference level or a net-net approach with a weighted legacy adjustment could factor out indirect human-induced changes in forest C stocks. The potential ability to use a technical correction, when different models or methods are used for the reference level and reporting time series, is an important proposal to ensure transparency and unbiased accounting of Forest Management in the post-2012 period.

In conclusion, this paper outlines a national approach for factoring out age class and indirect human induced effects using a projected reference level approach. This approach has been subject to international review and was deemed to be in accordance with principals set out in Appendix II of Decision 2/CMP.6. However, these are proxy approaches, given the limited current scientific understanding of indirect human induced effects on current and future forest sinks, in particular the influence of elevated CO_2 and N deposition (Ainsworth and Long 2005, Black et al. 2010). In addition, more research is required to further develop national capacity for reporting Forest Mangement C stock changes. Specific research needs include soil C stock changes (Wellock et al. 2011) and use of remote sensing technologies to estimate changes in forest areas (due to harvesting, deforestation and natural disturbances) at a higher spatial resolution than what is offered using the current national forest inventory.

There are several practical implications from this study, which include:

- The current sequestration of plantation forests is strongly influenced by management practices or policies, which may have occurred a long time ago. For example, historical fluctuations in afforestation rates could result in emissions 50 years later due to age-class shifts.
- Premature harvesting reduces the sequestration potential at the stand and national level.
- Harvesting results in a residual emission from the deadwood pool for ca. 30-years after harvest. Additional harvest of non-timber biomass, such as bundling and stump harvesting, would result in an even higher emission from national forests.

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Farm and farmer characteristics affecting the decision to plant forests in Ireland

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Abstract
Understanding the factors that influence farmers to enter forestry is important in order to develop efficient policies aimed at promoting greater rates of private planting. Using Ireland as a case study, factors affecting farmers' participation in farm forestry were evaluated. Specifically, a nationally representative panel dataset collected annually between 1995 and 2009 was used to model both farm and farmer related characteristics affecting the probability of farmers entering into forestry. Results suggest that there is significant heterogeneity among farm households in terms of farm forestry participation. Owners of larger farms and those in less-intensive farm systems were more likely to enter into forestry during the period 1995-2009. Age and the presence of children were negatively associated with farm forestry participation.

Keywords: *Farm forestry entry, forest policy, rural development, panel data.*

Introduction
Ireland has one of the lowest levels of forest cover in Europe at 11%, despite having a shorter rotation period for forestry than many other European countries (McCarthy et al. 2003). In 1996 the Irish government issued "Growing for the Future, A Strategic Plan for the Development of the Forestry Sector in Ireland". It set a target of achieving a productive forest area of 1.2 million ha by 2030, or 17% of the land area of the country (DAFF 1996). Up until the mid 1980s the State was the dominant force in Irish forestry as public afforestation accounted for almost 100% of the annual planting programme. Since then, the government has sought to significantly increase the rate of private planting through the introduction of a variety of government-supported packages to encourage private afforestation (Kearney 2001).

Much of the research on the factors affecting farmers' decision to convert land to forestry has investigated farmer behaviour in relation to policy objectives and farming context. As Wynn et al. (2002) point out, when it comes to modelling farmers' uptake of alternative non-primary agricultural related programmes, the emphasis has been on descriptive approaches rather than the quantitative modelling of farmer behaviour. Few attempts have been made to model the participation decision of farmers in forestry and most have done so using a static framework. Static binary choice models may be inadequate in analysing landowner participation in afforestation programmes. We used a panel data model for our estimation of farm-forestry participation in

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Ireland. Specifically, we utilised a 15-year panel dataset taken from the Irish National Farm Survey (NFS) that contained yearly information on approximately 1,200 farmers. Using this panel dataset, we examined the impact of both structural farm level variables as well as farmer characteristics driving farmers' decision-making in relation to farm forestry participation. There is a need to better understand the factors that affect farmers' decision making so that efficient policies and programmes can be designed to encourage greater rates of private planting. To provide a context for this study, some background information is also given on Irish forestry, especially the development of the private-sector planting programme.

Background

Forest cover in Ireland occupies just 11% (745,457 ha) of the total land area starting from a low base of 1% (70,000 ha) in 1920. This increase in forest cover is the direct result of successive government afforestation policies to promote the planting of forests. Prior to the 1980s private afforestation played a very small part of the overall afforestation programme accounting for 12,000 ha or 4% of the total area planted. Virtually all planting was carried out by the state (the Forest Service and its successor Coillte Teoranta, the Irish Forestry Board). Since 1980 a variety of incentives have been introduced by the Irish government and the EU to encourage private landowners to consider forestry as a worthwhile land-use alternative to agricultural production systems. These incentives are not available to the state sector. The result has been a dramatic reversal in the rate of afforestation between the state and private forestry sector (see figure 1). Since 2001, virtually all afforestation has been carried out by private individuals or institutions and private ownership of forest land has increased from 24% of the total forest area in 1980 to 46% (339,341 ha) in 2009 (Forest Service 2009).

The introduction of the Western Package Grant Scheme in 1981 marked the beginning of EU co-funded supports for private afforestation in Ireland. The EEC launched the Western Package Grant Scheme as an attempt to counter the depletion of forestry resources in the European community. The scheme was part-funded by the

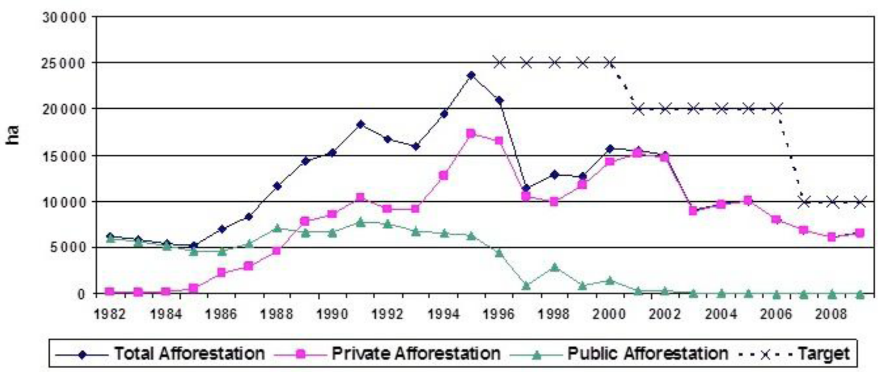

Figure 1: *Recent Irish afforestation levels.*

Irish government and made £18 million (€23 million) available in the form of grants to promote private afforestation. More specifically, the scheme provided grants to farmers that covered up to 85% of the establishment costs for converting to forestry and was available only in what were classified as disadvantaged areas in the Western part of the country. These supports for afforestation have since been improved and extended over time to all parts of Ireland. The "Forest Premium Scheme" was introduced in 1990 and it was the first scheme that attracted significant farmer interest. This scheme gave farmers annual payments for the first 15 years following afforestation on unenclosed land and 20 years on enclosed land, in addition to providing a grant to cover all the costs associated with forest establishment (Gillmor 1998, Farrelly 2008).

The introduction of the Forest Premium Scheme provided the most important new incentive for forestry development in Ireland to date. It provided compensation for loss of agricultural income for up to 20 years, coinciding approximately with the time that income from harvesting thinnings might begin to accrue. Forestry was then seen as an alternative to some traditional types of farming and the scheme applied to all of Ireland. The range of grants available differed based on the quality of land planted and the type of species planted. A further supplement was provided to landowners who planted areas greater than 6 ha. More recently the CAP Afforestation Scheme, introduced in 2003, increased the incentives to plant broadleaf species by offering a considerably higher premium payment than that offered for planting conifers.

The Forest Environment Protection Scheme (FEPS) was introduced on a pilot basis in 2007, with the aim of rewarding farmers who were already participating in an agri-environmental scheme namely REPS (the Rural Environment Protection Scheme). Farmers were encouraged to include additional environmental measures in their forests to improve both biodiversity and recreation potential. In addition to the normal afforestation premium, a FEPS premium of between €150 and €200 per ha for five years was made available to farmers in REPS who planted under the FEPS scheme. This meant that a REPS farmer who planted 8 ha of oak in FEPS could receive up to €759 per ha for five years, followed by €559 per ha for the remaining 15 years, with all premiums being tax-free. A plantation threshold area of between 5 and 8 ha applied. The scheme was designed to encourage greater uptake of farm forestry and initially proved very popular. In 2008 and 2009, almost half of all new planting was carried out under the FEPS scheme. However, since the closure of the REPS scheme in July 2009, participation in the scheme dropped to 40% by 2010 and is expected to drop further as farmers who are no longer in REPS are also no longer eligible for FEPS (Ryan 2011).

Factors affecting the decision to plant

Prior to 2005, Irish farmers could potentially avail of a number of coupled premium payments, such as the special beef premium or area-aid payments, to supplement their market-based income. These payments were decoupled from farm-production measures in 2005 to curb over-production and to reduce the trade-distorting and inefficiency effects of the CAP (Falconer and Ward 2000, Swinbank and Daugbjerg 2006, Howley et al. 2010). With the introduction of decoupling, payments that were paid previously on the basis of the number of eligible animals, or area under a crop, were now replaced with a single annual decoupled payment, referred to as the Single Farm Payment (SFP). Of particular interest to the forestry sector was that this new system of support allowed farmers to plant up to 50% of their land and still receive their SFP. In 2009, forestry was deemed to be eligible for SFP, which meant that farmers could plant up to 90% of their land and still retain the full SFP. However, despite the potential gain accruing from grants, such as the forest premium, as well as the potential future market returns from clear felling, Irish afforestation levels have actually been declining from 10,030 ha in 2005 to 6,648 ha in 2009 (Breen et al. 2010).

McCarthy et al. (2003) examined the impact of various policy incentives, such as planting grants and forest premiums as well as the returns available from harvesting, on farmers' decision to enter into forestry. The study found that increasing the planting grant was a more cost-effective measure for increasing the rate of private planting than increasing the level of the forest premium. In comparison the effect of the financial returns from timber sales, while statistically significant, was relatively low, perhaps because it could take 40 years or more to realise these revenues.

Constraints within the planting approvals system such as planning regulations and the length of time taken for the approvals process are likely to exert a negative influence on participation rates in farm forestry. Perhaps one of the most significant factors behind farmers' reluctance to convert their land to forestry in Ireland in recent times has been the significant increase in the value of agricultural land from 1992 to 2007 (Breen et al. 2010). Conversion from agriculture to forestry is a permanent decision in Ireland, due to the legal requirement under the 1946 Forestry Act to replant after clearfelling. The requirement to reforest was introduced with the objective of protecting the State's investment in forestry and to discourage large-scale deforestation (Malone, 2008). Given the high prices that were paid for agricultural land in recent years (Ganly 2009), the requirement to replant acted as a major obstacle to afforestation. The recent decline in land prices evident since the start of 2008 could make forestry a relatively more attractive financial proposition and in turn lead to a boost in the level of private farm afforestation. That said, even when the high land prices that existed in Ireland from the late 1990s to 2008 are accounted for, it would appear that the core reason behind the relatively low levels of afforestation in Ireland is due to negative cultural attitudes towards forestry (McDonagh et al. 2010).

Behan (2002) has shown that in 2001 the net present value (NPV) of forestry returns in Ireland exceeded that of beef and sheep enterprises in all regions, particularly in the western regions of Ireland. The results of the NPV analysis, demonstrated that the potential financial returns from forestry generally exceeded that which could be obtained from cattle and sheep farming. Therefore from a purely financial perspective, there should have been a much greater uptake of farm-forestry than that which occurred. Frawley and Leavy (2001) found that Irish farmers perceived the main reason for not converting land to forestry was that their farm is "too small/need the land". More recent work conducted by McDonagh et al. (2010) echoed the earlier findings of Frawley and Leavy (2001). They found that of the 48% of the farmers who stated that they would not plant, the most important barrier to planting land was that they "needed their land for agriculture". This occurred despite the introduction of the single farm payment (SFP), which had allowed farmers to plant a large proportion of their land without losing any payments.

Earlier work conducted by Ní Dhubháin and Gardiner (1994) and O Leary et al. (2000) reported a negative cultural attitude on the part of Irish farmers towards forestry. For example, Ní Dhubháin and Gardiner (1994) reported that of those farmers who stated an intention to plant land in the future, 58% said that their land was good for nothing else; while 39% of those who said they would not plant believed they did not have suitable land for forestry (i.e. they felt their land was "too good for forestry"). Similarly O Leary et al. (2000) found that the main reason behind farmers' negative attitudes towards forestry was not dissatisfaction with the low financial rewards, but rather a negative cultural bias towards forestry. Forestry has traditionally not been seen as an integral part of traditional agriculture and most farmers consider forestry only as an alternative land-use for their worst land. Negative cultural attitudes towards forestry have also been widely reported in other countries. Selby and Petajisto (1995), in a study conducted in Finland, found that there was a perception that converting land to forestry can sever the dynamic historical process involved in the creation of agricultural landscapes and thereby having a negative effect on local communities. Similarly in the UK, Watkins et al. (1996) found that most farmers did not want woodland on their farmland, as they saw their land as being exclusively a preserve for agricultural production.

Farm-forestry participation continues to be a topic of research internationally. Nagubadi et al. (1996) analysed private forest landowners' participation in forestry assistance programmes in Indiana, USA. A probit model was used on data collected from a random sample of 329 Indiana landowners. The results of the analysis revealed that total land owned, access to government sources of information, and membership in forestry organizations all had a positive impact on the probability of landowners' participating in private forestry programmes.

Other research carried out in the US aimed at modelling the major factors affecting private forestry participation included Bell et al. (1994), Straka et al. (1984), Konyar and Osborn (1990) and Joshi and Arano (2009). Bell et al. (1994), for instance, employed a random utility model to determine the probability that a landowner will choose to participate in the Tennessee Forest Stewardship Programme. Results from the study indicated that attitudes and knowledge of forestry programmes may be more influential in a landowner's decision to participate than monetary incentives. Many of the empirical studies that have examined landowner participation in forestry programmes have relied on a simple static binary choice model. Independent variables included owner demographics (e.g., income, education) and land features (e.g. acreage). Using these models, landowner participation in private afforestation in the US has been found to be positively associated with total area owned, interest in timber production, income, and location of residence on the landowner's woodland (Straka et al. 1984 and Konyar and Osborn 1990).

Methods

The data source employed for this research was the Irish National Farm Survey (NFS)

1995 to 2009, which was set up in 1972 and has been published on an annual basis since then. The NFS is collected as part of the Farm Accountancy Data Network of the European Union (FADN 2012). It determines the financial situation on Irish farms by measuring the level of gross output, costs, income, investment and indebtedness across the spectrum of farming systems and sizes. This information is made available to the EU Commission in Brussels and is a database for economic and rural development research and policy analysis (Connolly et al. 2009). A random sample of approximately 1,200 farms is surveyed each year and the farm system variable is broken down into six different farm systems.

The method of classifying farms into farming systems, used in the NFS is based on the EU FADN typology set out in the Commission Decision 78/463 (Connolly et al. 2009). The system titles refer to the dominant enterprise in each group based on Standard Gross Margins (SGMs). Within the NFS, the farm system variable is broken down into six different categories as follows: Dairying, Dairying and Other, Cattle Rearing, Cattle Other, Mainly Sheep and Tillage Systems. To examine the effect of farm system type on forestry decisions, we grouped the system variables relating to livestock production (either cattle or sheep) into one dummy variable (Livestock Production). We then compared the effect of being in either Livestock Production or in the Dairying and Other farm systems on the probability of entering into forestry, relative to being in the Dairying or Tillage-farm systems. We used Tillage and Dairy farm systems as the reference category, as these farms are relatively more intensive in nature and generally more productive than the Livestock or Dairying and Other farm systems (see Connolly et al. 2009).

Using the NFS data collected over the 15-year period from 1995 to 2009, the participation decisions of farmers in relation to forestry were analysed. Some farmers dropped out permanently from the survey, while others dropped out in one year but re-entered the following year, so the dataset was unbalanced. New farmers were introduced to the survey during the period to keep the sample representative and at approximately 1,200. On average farm respondents participated in the sample over the reference period for 9.36 years. Once a farm remained in the sample for 2 years or more (which need not be concurrent) it was used in the panel data model of farm forestry participation.

The dependent variable (farm forestry entry) took a value of 1 if a farmer has entered into forestry during the period 1995-2009, but was 0 otherwise. There were 90 individual farm households that entered into forestry during the reference period. The model was used to determine if there are any farm or farmer characteristics that distinguished farmers who entered into forestry from farmers that did not do so. Given the structure of the dataset, we were able to use a random effects model to control for unobserved heterogeneity (see Greene 2003 and Baltagi 2008 for a discussion of random effects models).

Results and discussion

The coefficient estimates and associated standard errors of the random effects logit model are presented in Table 1. All farm characteristics examined were found to be statistically significant at the 5 or 10% significance level. Firstly, other things being equal, the larger a farm was the more likely that the owner had planted part of their land. This is in accordance with our a priori expectations, and is in agreement with the findings of Frawley and Leavy (2001) and McDonagh et al. (2011). That is, the main barrier to converting land to forestry was related to farm size; those farming smaller holdings felt that their farm was too small to accommodate forestry and believed that all of their land was needed for agriculture. The variable farm size squared was bordering statistical significance and was negative which would suggest that, while farm size has a positive effect on the decision to plant, this effect diminishes as farms get larger (i.e. the effect of going from 100-150 ha is less than going from 50-100 ha). These results also agree with recent NFS survey results for the cohort of farmers who were considering planting in the next three years (see Ryan et al. 2008, Ryan 2011). Almost half of the farmers who stated an intention to plant were livestock farmers on relatively large farms. Research results from other countries also confirm these findings (Miranda 1989, Loyland et al. 1995).

The results from the logit model also suggested that landowners entering into forestry are more likely to be drawing down premium payments from other farm activities such as headage payments, disadvantaged area payments, or since the introduction of decoupling, the single farm payment. This may reflect the greater awareness of the prevalence of subsidy payments to support agricultural activity or perhaps a greater willingness on the part of these farmers to engage in non-traditional farm activities that do not just provide a market return.

Both "Livestock" and "Dairying and Other" factors had statistically significant and positive effects on the probability of farmers entering into forestry (Table 1). This means that farmers in these more extensive farm systems are more likely to enter into forestry than farmers in the Dairying and Tillage farm systems. This is in keeping with survey research discussed earlier which outlined how farmers in relatively more productive farm types often feel that their land is too good for forestry, irrespective of the financial returns. In addition, relatively more productive farms would be under less pressure to consider alternative or perhaps less traditional ways of increasing revenue on the farm, such as converting land into forestry. Farmers with higher stocking rates were less likely to convert to forestry. This also would support the view that owners of relatively more intensive farm types are less likely to consider putting land into forestry.

In addition to structural factors of farms that may be associated with the likelihood of converting to forestry, the effect of farmer-specific variables on the probability of entering into forestry was also examined. Given the relatively long time frame for receipt of timber revenue from clear felling, it was hypothesised that older farmers would be less likely to consider forestry as a worthwhile investment. The results in Table 1 suggest that a farmer's age has a negative association with entry into farm forestry. A negative relationship between age and forestry activity has also been reported in other studies conducted outside Ireland (Romm et al. 1987, Kuuluvainen and Salo 1991, Joshi and Arano 2009). Given that the average age of farmers is increasing in Ireland (e.g. more than one third are aged over 60), this is likely to be a significant barrier to increasing land in forestry use. It may therefore be worthwhile for policy makers to consider other investment models, whereby farmers receive at least part of the payments from clearfelling upfront. Interestingly farmers with children were also less likely to have entered into forestry during the period 1995-2009. This could be attributable to the presence of a farm heir to continue on the farm business.

Conclusions

Forestry plays an increasingly important role in rural development, mainly because it helps to diversify farm income, but also through the provision of rurally-based employment, both of which contribute to rural stabilisation and viability. Irish forestry policy emphasises the importance of private planting and gives farmers a central role in the expansion of the national forest cover (DAFF 1996), but farmers' uptake of the forestry option has lagged far behind national targets. This study utilised a nationally representative panel dataset to provide a better understanding of the factors affecting the probability of farmers entering into forestry.

The results of previous research has determined that changes in the level of payments, the forestry market margin as well as returns from competing agricultural alternatives will affect rates of afforestation (Barrett and Trace 1999, Clinch 1999, Beach et al. 2005, McCarthy et al. 2003). This paper focused on examining the impact of characteristics of the farm and the farmer on the decision to enter into forestry. The findings suggest that larger farms, those in relatively less intensive farm systems and with lower stocking rates were less likely to enter in farm forestry. In addition to farm structural factors, this study also found that relatively older farmers and those with children were also less likely to enter into farm forestry. Modelling the factors affecting farmers' decision to enter into forestry enables the understanding of the differences between various types of landowners. This should in turn help policymakers and forest extension professionals to design policies and programmes that efficiently promote farm-forestry participation.

Table 1: *Random effects logit model of entry into Farm Forestry. Significant (P<0.10) values are shown in bold text.*

Parameters	Coefficient	Std. error	P-values
Farm size	0.0129	0.0068881	**0.061**
Farm size squared	-0.0000364	0.0000222	0.101
Direct payments	0.0000144	6.84e-06	**0.035**
Livestock production (dairying and tillage farm system is the reference category)	1.291665	0.4504018	**0.029**
Dairying and other farm system (dairying and tillage farm system is the reference category)	0.9837207	0.5203648	**0.013**
Stocking rate	-0.8223182	0.2604429	**0.002**
Age	-0.0180621	0.0109809	**0.100**
Children (no children is the reference category)	-0.5045422	0.305396	**0.099**
Married (single is the reference category)	0.2678904	0.3248981	0.410

Practical implications

- Results suggest that owner and farm property characteristics strongly affect the probability of farmers entering into farm forestry.
- Farm size appears to play an important role with those in relatively larger farms much more likely to enter into forestry.
- Farmers predominantly involved in livestock rearing and those with relatively lower stocking rates are more likely to convert land into forestry.
- Older farm operators and those with children are less likely to plant.
- Identifying farmers most likely to participate in farm forestry can allow policymakers and extension services to efficiently target efforts at those most likely to adopt.

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How can forest management benefit bird communities? Evidence from eight years of research in Ireland

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Abstract

An extensive programme of research on the breeding bird assemblages of Irish forests has been undertaken since 2001 to improve our understanding of the ways in which forest management can influence bird populations. Data on bird communities were collected from 115 sites across the island of Ireland. The sites included monoculture plantations at various stages of the forest cycle, commercially mature mixed species plantations, native woodlands and open non-forest habitats. Although this work comprised several discrete studies, the overarching aim was to investigate ways in which commercial forest plantations could be managed to improve their value for birds. The bird communities of some open habitats, including low intensity agricultural land and peatland, can be negatively affected by afforestation, but afforestation has the potential to have a more positive impact on the bird communities of intensively managed grasslands. Bird assemblages of native oak (*Quercus* spp.) and ash (*Fraxinus excelsior* L.) woodlands are more diverse than those of commercially mature conifer plantations and provide a reference against which to compare plantation forests. The inclusion of native broadleaved trees in conifer plantations can be beneficial for bird populations, at least in part due to diversification of forest vegetation structure. Shrub cover, which is associated with higher bird species richness, is prominent in pre-thicket plantation forests, particularly in the second rotation. The loss of understorey structure after canopy closure leads to a less diverse bird assemblage in the mid to late stages of the forest cycle. In general, forest management practices that promote growth of non-crop vegetation and presence of deadwood, thereby enhancing structural complexity, increase the quality of forest habitats for bird communities. In this paper we provide a summary of the findings from the first eight years of these studies, and discuss their application in achieving "Sustainable Forest Management".

Keywords: *Afforestation, birds, biodiversity, conservation, forest management, growth stage, non-crop vegetation.*

Introduction

The Irish pollen record indicates a reduction in forest cover starting with the arrival of Neolithic farmers about 6,000 years ago, and continuing until the late 19th century when forests accounted for just 1% of Ireland's land area (Mitchell 1995, Rackham 1995, Cole and Mitchell 2003, Mitchell 2006). From the beginning of the 20th century, forest cover began to increase, predominantly due to the establishment of conifer plantations. Rapidly growing conifer species now dominate forested lands in Ireland,

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which cover around 10% of Ireland's total land area (Forest Service 2007). By contrast, native woodlands account for only 1% of Ireland's land surface area. Plantation forests therefore constitute the majority of forested habitat currently available to woodland flora and fauna in Ireland. However, although Ireland's native woodlands (those comprised of native species and not intensively managed for timber) are limited in their spatial extent, their value in terms of the biodiversity they support is relatively high, providing a reference point against which more recently established forests can be compared.

Forest management in Ireland over much of the 20th century focused almost entirely on wood production. In recent decades, however, the concept of "Sustainable Forest Management" (SFM) has gained increasing recognition with both the forest industry and statutory regulating and grant-aiding bodies. The concept of sustainable forest management in Europe was developed by FOREST EUROPE and contains guidelines and criteria to secure the optimal balance of goods and services (Rametsteiner and Mayer 2004). The member countries have agreed on the following joint definition of sustainable forest management: *the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfil, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems*. Current obligations arising from international agreements and Irish society demand that modern forests be multifunctional, providing commercially viable timber yields in tandem with ecological and social services, which include maintenance of biodiversity, climate change mitigation and nature conservation (McAree 2000). Successful delivery of these services requires knowledge of the biota and prevailing ecological processes that underpin the potential environmental benefits of commercial forests. While there is still an emphasis on forest expansion, the nature of the forest estate in Ireland is changing, as first rotation forests are harvested and second rotation forests are planted to replace them. Conventional commercial conifers, such as Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and lodgepole pine (*Pinus contorta* Dougl.) continue to be planted, but their dominance in the Irish forest estate is diminishing. Grant-aided new plantings are now required to incorporate a variety of tree species in accordance with the Irish Forest Biodiversity Guidelines (Forest Service 2000). The Irish National Forest Standard, the Code of Best Practice and Environmental Guidelines assist the Forest Service in implementing the environmental aspects of SFM in Ireland. Non-compliance with these guidelines can result in the withholding of grants and felling licences (McAree 2000). Many native broadleaved tree species, which are relatively unproductive in terms of their timber yield, are now included in commercial plantings, as well as in forests established as part of dedicated initiatives to increase their abundance, such as the Native Woodland Scheme. These recent developments provide an opportunity for the forest industry to achieve new ecological standards, and to ensure compliance with international agreements, using research-based knowledge.

Bird diversity is an important component of forest ecosystems (Sekercioglu 2006), influencing seed dispersal (Gómez 2003, Martínez et al. 2008), pollination (Cronk and Ojeda 2008, Mortensen et al. 2008) and exerting top-down control over insect communities including pests (Skoczylas et al. 2007, Gunnarsson et al. 2009). The increase in plantation forests across Europe (FAO 2007), has coincided with reported declines in the populations of some woodland bird species across the continent (Fuller et al. 2005, Gregory et al. 2007), though these trends vary between regions (Klvaňová et al. 2009). Ireland's woodland bird fauna comprises fewer species than are found in European countries (Fuller et al. 2007, Sweeney et al. 2012). Reasons for this include Ireland's long history of deforestation, which probably led to the loss of forest associated species such as capercaillie (*Tetrao urogallus*) and great spotted woodpecker (*Dendrocopus major*) (Yalden and Carthy *2004*); the relatively small size and isolation of the island - attributes that typically result in lower species richness (MacArthur and Wilson 1967); the competitive advantage of resident species over migrants resulting from Ireland's mild climate (O'Connor et al. 1986); and the lack of sufficiently large source populations for colonisation to take place (Kelly 2008). Although two of the four races of birds endemic to Ireland (coal tit and jay) are predominantly woodland birds, Irish forest bird communities are mainly comprised of generalist bird species that are also common in open habitats (Nairn and Farrelly 1991, Pithon et al. 2004, O'Halloran et al. 2011). A small number of common, generalist bird species dominate our forest bird communities, some examples of which are listed in Table 1.

Plantation forests can, however, potentially provide habitats for many birds that utilise naturally occurring woodland habitats (Brockerhoff et al. 2008). Although stands of native tree species support more local biodiversity than do monocultures of exotic conifers, in some cases exotic conifer plantations can support bird communities as diverse as those in native tree stands (Archaux and Bakkaus 2007). Direct comparisons between plantations and more natural woodlands are useful in identifying woodland features that contribute to bird diversity. As management is one way to influence the utility of plantations to birds (Lantschner et al. 2008, Luck and Korodaj 2008, Calladine et al. 2009), such comparative studies may reveal ways in which plantations can be improved to enhance their value to birds.

Prior to 2000, few studies of biodiversity had been conducted in Irish forests, particularly in commercial plantations. Research to address this information gap was undertaken between 2001 and 2006 by the COFORD (National Council for Forest Research and Development) and EPA (Environmental Protection Agency) funded BIOFOREST research project. This was followed by the COFORD funded PLANFORBIO programme, which will run until 2013. These projects represent over 10 years of comprehensive research on the biodiversity of Ireland's forests, including bird diversity. Detailed information on the methodologies employed in these studies can be found in the relevant peer-reviewed and published papers (O'Halloran et al. 2002, Pithon et al. 2004, Wilson et al. 2006, Wilson et al. 2009, Sweeney et al. 2010a, Sweeney et al. 2010b, Sweeney et al. 2010c, Wilson et al. 2010, Sweeney et al. 2011, Sweeney et al. 2012, Wilson et al. 2012). This paper reviews the results from 115 survey sites used during the first 8 years of this research (Figure 1), highlighting findings that may be of interest and relevance to forestry managers and practitioners aiming to enhance the value of forest plantations for birds.

Table 1: *Ecological characteristics of the bird species mentioned in this paper, described by habitat association (F=Forest, BF=Broadleaved Forest, CF=Conifer Forest, Gen =Generalist, P=Peatland, Gr=Grassland), tolerance to afforestation (+ = tolerant, - = intolerant). For further information see (Nairn and O'Halloran 2012).*

Common name	**Scientific name**	**Habitat association**	**Afforestation tolerance**	**Migrant/ Resident**
Capercaillie	*Tetrao urogallus*	F	NA	M
Great spotted woodpecker	*Dendrocopus major*	F	+	R
Jay	*Garrulus glandarius hibernicus*	BF	+	R
Blackbird	*Turdus merula*	F, Gen	+	R
Robin	*Erithacus rubecula*	F, Gen	+	R
Wren	*Troglodytes troglodytes*	F, Gen	+	R
Chaffinch	*Fringilla coelebs*	F, Gen	+	R
Meadow pipit	*Anthus pratensis*	P, Gr	-	R
Skylark	*Alauda arvensis*	P, Gr	-	R
Hen harrier	*Circus cyaneus*	P, F	+[1]	R
Merlin	*Falco columbarius*	P, F	?	R
Red grouse	*Lagopus lagopus*	P	-	R
Quail	*Coturnix coturnix*	P, Gr	-	M
Golden plover	*Pluvialis apricaria*	P, Gr	-	M
Lapwing	*Vanellus vanellus*	P, Gr	-	R
Dunlin	*Calidris alpina*	P	-	M
Curlew	*Numenius arquata*	P, Gr	-	M
Redshank	*Tringa totanus*	P, Gr	-	M
Whinchat	*Saxicola rubetra*	P	+[1]	M
Stonechat	*Saxicola torquata*	P, F	+[1]	R
Ring ouzel	*Turdus torquatus*	P	-	M
Twite	*Carduelis flavirostris*	Gr	-	R
Goldcrest	*Regulus regulus*	CF, Gen	+	R
Coal tit	*Periparus ater*	CF, Gen	+	R
Blackcap	*Sylvia atricapilla*	BF	+	M
Blue tit	*Cyanistes caeruleus*	BF, Gen	+	R
Bullfinch	*Pyrrhula pyrrhula*	BF, Gen	+	R
Chiffchaff	*Phylloscopus collybita*	BF	+	M
Great tit	*Parus major*	BF, Gen	+	R
Long-tailed tit	*Aegithalos caudatus*	BF	+	R
Treecreeper	*Certhia familiaris*	BF	+	R
Willow warbler	*Phylloscopus trochilus*	F	+[1]	M

[1] These species are tolerant of afforestation only during the pre-thicket growth stage, before the forest canopy closes.

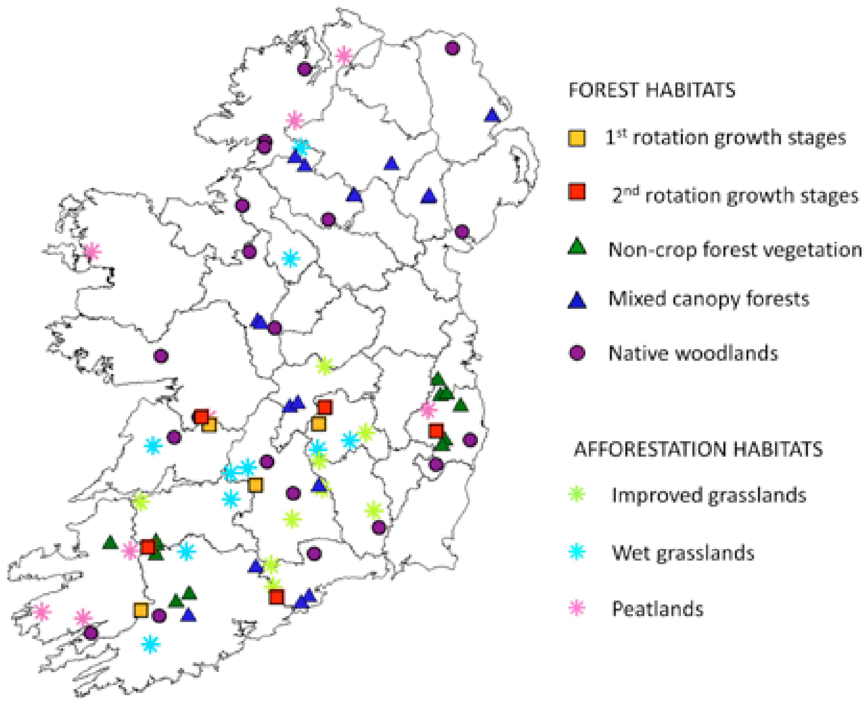

Figure 1: *Location of the 115 forest and afforestation habitat sites used in the studies reviewed in this paper. Each of the square symbols represents a cluster of four 1st or 2nd rotation forest sites at different growth stages (pre-thicket, thicket, mid-rotation and commercially mature).*

Forest management and Irish bird communities

Afforestation of open habitats

Afforestation fundamentally changes ecosystem structure, and the impact of forest plantations on bird communities depends on the type of habitat that is replaced (Thompson et al. 1995). Up until 1986, peatland (Figure 2) was the most commonly afforested land type in Ireland (Wilson et al. 2012). Since then afforestation has predominantly taken place on gley soils, with rates of afforestation on other soil types (including agriculturally improved soils see Figure 2) remaining low.

Of all the commonly afforested habitats, the bird assemblages of peatland habitats are the most distinct from those of plantations (Wilson et al. 2012). Most grassland habitats (Figure 2) support very low densities of birds in open areas, and birds are many times more abundant in hedgerows or patches of woodland and scrub. However, some open habitat specialists present in these grassland habitats, such as meadow pipit (*Anthus pratensis*) and skylark (*Alauda arvensis*) (Table 1), are intolerant of afforestation (Wilson et al. 2012). The quality of grassland habitats for birds is negatively related to the intensity of agricultural management. Most of the bird species that breed in agriculturally improved grasslands are birds that can also be

Figure 2: *From left to right: Peatland, Wet grassland and Improved grassland habitats (Photos: Mark Wilson and Catherine Bushe).*

found in forest plantations. Because of its relatively low value for bird communities, afforestation of intensively managed grassland has a more positive impact on bird diversity than afforestation of low intensity agricultural grassland, particularly where the latter has high levels of in-field shrub cover or supports open habitat specialists (Wilson et al. 2012). Peatland sites tend to have low bird diversity, but support relatively high densities of the open habitat specialists, meadow pipit and skylark.

Among the birds that breed in peatland sites are several species of conservation importance, including birds of prey, game-birds, waders and song-birds (Table 1). The bird assemblages of peatland or unimproved agricultural sites proposed for afforestation should be examined prior to afforestation, to ensure that important open habitat species are not negatively affected.

Native woodlands and non-native plantations

Many aspects of forest management can affect the value of forests for birds, including planting, fertiliser application, pest and weed control, thinning, harvesting, and creation of associated habitats and structures such as roads (Avery and Leslie 1990, O'Halloran et al. 2002, Roycroft et al. 2008, Calladine et al. 2009). Unmanaged native oak (*Quercus* spp.) and ash (*Fraximus excelsior* L.) woodlands (Figure 3) support more diverse bird assemblages than both mid-rotation and commercially mature Sitka spruce plantations (Sweeney et al. 2010a). The most common two bird species in both mature and maturing conifer plantations in Ireland are goldcrests (*Regulus regulus*) and coal tits (*Periparus ater*), which feed predominantly on small invertebrates that can be plentiful in such habitats (Gibb 1960, Sweeney et al. 2010a). Removing these two species from the statistical analysis reveals that the densities of all other bird species are twice as high in native woodlands as they are in conifer plantations, even when the latter are relatively mature (Figure 3). This is principally due to higher densities in native woodlands of several bird species associated with broad-leaved trees and shrubs (Table 1).

There are several reasons that native woodlands are better quality habitats for these species than conifer plantations. The influence of deciduous trees allows for greater structural complexity of sub-canopy vegetation due to increased light penetration through the forest canopy. Greater structural complexity creates a wider range of foraging and nesting opportunities for many bird species. There is a substantial body of evidence in Britain (Fuller et al. 2007, Gill and Fuller 2007, Hopkins and Kirby 2007) and Europe (Cherkaoui et al. 2009, Nikolov 2009) highlighting the importance of vegetation structure to woodland birds (Pienkowski et al. 1998, Ferris et al. 2000). In Ireland, the number of bird species supported by forests has been shown to be positively associated with understorey cover (Wilson et al. 2006, Sweeney et al. 2010c, Wilson et al. 2010). Dense canopies suppresses understorey vegetation in plantation forests (Smith et al. 2008), so mature conifer plantations tend to have low structural diversity in the field and shrub layers (Ferris et al. 2000). This results in lower quality habitat for birds than unmanaged, structurally heterogeneous native woodlands. Measures that reduce canopy cover and allow more light penetration would therefore ultimately benefit bird diversity (Quine et al. 2007, Ding et al. 2008). Increasing the structural complexity of forests is likely to increase their value for birds.

Tree species mixtures

Tree composition of forest plantations may be important for biodiversity, with mixed conifer-broadleaf (Figure 4) stands often holding richer bird communities than pure conifer plantations (Donald et al. 1998, Farwig et al. 2008, Felton et al. 2010, Sweeney et al. 2011). A study of the bird communities of Norway spruce plantations in Ireland found that diversifying these forests with either oak or Scots pine (*Pinus sylvestris* L.) had only a modest effect on bird communities (Sweeney et al. 2010b). However bird species composition in intimately mixed stands was similar to that found in native woodlands composed entirely of either Norway or Sitka spruce (Sweeney et al. 2011). Possible reasons for this include the greater level of shrub cover in the mixed forests (which may be a consequence of increased light penetration due to a more open canopy), and also the direct influence of the native tree species. Both of these factors increase structural complexity beyond the levels found in typical pure conifer stands. In the case of Norway spruce and oak mixes, the influence of the oak component probably did not reach its full potential, due to oak trees being out-competed by the faster growing conifers. In most of the oak mixes studied, this resulted in planted oak trees being relegated to the sub-canopy layer, which reduced their size and influence on forest vegetation and bird communities. Oak planted in an intimate mix among conifers may therefore be less beneficial to birds than larger patches of oaks interspersed among a stand. When planted in clumps, oaks will be less affected by shading from surrounding conifers, allowing them to contribute to the forest canopy and be of greater benefit to local bird assemblages (Sweeney et al. 2010b).

Non- crop vegetation

The lower diversity of bird communities in closed canopy plantations, relative to native woodlands, is in part due to the scarcity of under-canopy, non-crop vegetation and broadleaved shrubs and trees (Figure 5). As mentioned earlier the opportunities for such vegetation to develop is typically limited by the low levels of light in closed canopy plantations. Bird diversity at the stand and forest scales was positively related to the percentage cover of deciduous, broadleaved trees non-crop vegetation in Irish

Figure 3: *From left to right: native oak woodland, native ash woodland and mature non-native Sitka spruce plantation forest (Photo: Mark Wilson).*

Sitka spruce plantations (Wilson et al. 2010). Non-crop vegetation in roads, rides and other unplanted areas was also associated with higher bird diversity. The higher bird species richness in these areas was, in large part, due to the presence of species that are known to be associated with broadleaves, and so responded to the increase in the cover of shrubs and broad-leaved trees (Figure 5). Non-crop vegetation can also have a positive effect on birds by enhancing the structural complexity of forest vegetation. This suggests that providing an opportunity for native trees and shrubs to grow by leaving unplanted areas in stands may partly compensate for the simpler structure and lack of broadleaved vegetation in areas of closed canopy conifers (Roycroft et al. 2008, Wilson et al. 2010). The magnitude of the positive effect of such unplanted areas will likely be determined by their overall size, with larger areas providing habitat for a greater number and diversity of birds. When incorporating an unplanted or open area in a forest there are advantages both of dispersing this area between a number of individual small spaces (to maximise the influence of non-crop vegetation on the wider forest (Bibby et al. 1989)) of configuring it as a single large area (to better suit species with large habitat requirements (Langston et al. 2007)).

Rotation and growth stage

Several studies have examined the effect on bird assemblages in plantation forests of growth stage (from planting through to harvest) and rotation (Patterson et al. 1995, Donald et al. 1998, Wilson et al. 2006, Sweeney et al. 2010c). Differences between commercial plantation rotations are generally not as marked as those between different growth stages, which are in large part due to changes in percentage cover of shrubs over the commercial forest cycle (Wilson et al. 2006). In Ireland, few areas of conifer forest are left unharvested beyond 50 years of age and, as a result, features associated with old-growth forests such as high volumes of standing and lying deadwood, tree hollows and regenerating areas of shrubs and sub-canopy trees in gaps left by fallen trees, are rare in Irish forests (Sweeney et al. 2010c). Old growth forests may help the re-establishment of the great spotted woodpecker (Coombes et al. 2009). Nevertheless, differences have been reported between the bird communities of first and second rotation forests. Throughout the second rotation, but especially during

Figure 4: *Mixed Norway spruce and oak plantation forest (Photo: Linda Coote).*

the pre-thicket stage, levels of non-crop shrub cover are higher than in equivalently aged, first commercial rotation forests. As a result, several species of birds that breed in shrub-rich habitats are more abundant in second rotation pre-thicket forests (Figure 6) than in recently established afforested sites. Migrant songbird species have been found at significantly lower densities in closed canopy than in Thicket and Pre-thicket forests (Figure 6). The bird communities of these early stages are markedly distinct from those of closed canopy plantations. In addition to holding high densities of several migrant songbird species, second rotation pre-thicket stands also support resident species of conservation concern (Table 1). However, these species are not found in plantations following canopy closure at the mid rotation stage (Figure 6), but are replaced by a more generalist bird community, with high densities of just a few common species.

Conclusions

Afforestation profoundly changes the bird communities of many open habitats, particularly following canopy closure. The establishment of forests in intensively-managed grassland sites is preferable to afforestation of marginal habitats, such as species rich grassland, intact peatland habitats or habitats with a high percentage cover of shrubs. The low species richness of closed canopy Sitka spruce monoculture plantations, relative to that of native Irish woodlands, demonstrates the importance of structural complexity and components such as understorey cover for bird species richness. Mixed plantations support more diverse bird communities than monocultures, due to their increased structural diversity. If planting slow growing trees such as oak as a diversifying mix component within a conifer plantation, their contribution to forest biodiversity can be enhanced by ensuring that they do not become outcompeted by the more vigorous conifer component. The persistence of trees through a number of rotations may improve availability of nest sites and foraging habitat for several woodland species, including hole-nesting species such as the recently colonised great spotted woodpecker. The presence of a variety of forest age classes will increase the chance of required habitat conditions being available for many terrestrial bird species in Ireland. Additionally, leaving unplanted areas (e.g. forest margins, wide rides and glades) in and around plantations and establishing plantations near to existing broadleaved woodland may have an overall positive effect on forest bird communities. Forest management strategies should particularly target the closed canopy stage to increase habitat heterogeneity and enable plantations to benefit a wider range of species.

Management recommendations

1. Use improved grassland sites for afforestation where possible.
2. Carry out more extensive thinning in mid-rotation forests.
3. Plant broadleaved trees in patches throughout mixed species plantations or with slower growing, more open canopy species such as Scots pine.
4. Allow some trees to persist through several rotations (to complete their life cycle).
5. Include all growth stages of the forest cycle within a forested landscape.
6. Leave vegetation to develop in unplanted areas within forest plantations.

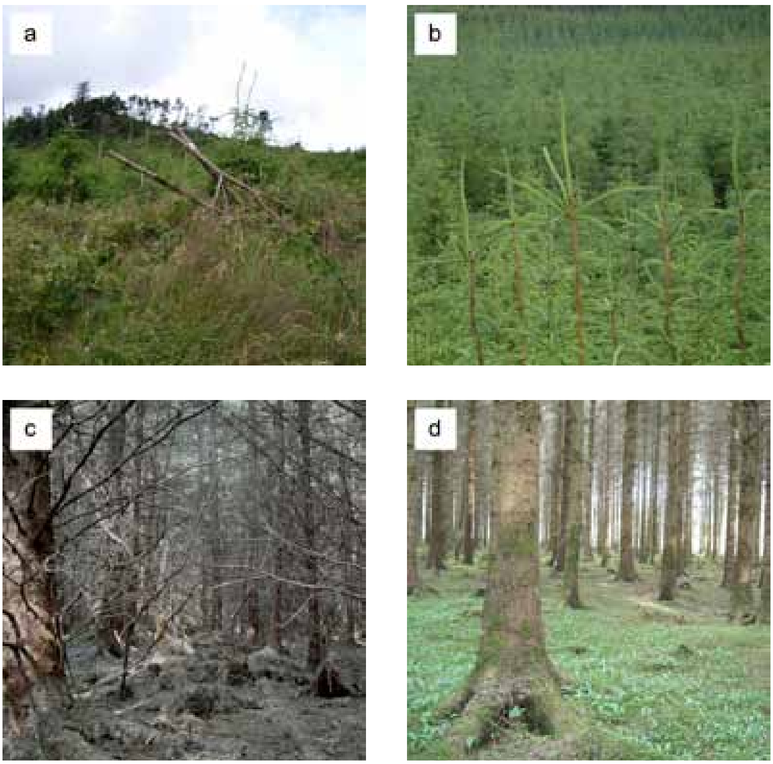

Figure 6: *Different growth stages of Sitka spruce forest: a. pre-thicket, b. thicket, c. mid-rotation and d. commercially mature (Photo: Mark Wilson).*

By implementing at least some of these management recommendations the bird communities of Irish forests should benefit from a more diverse and heterogeneous forest structure. This will enable plantation forests to realise their potential as important conservation areas for Ireland's biodiversity.

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Validating generalised diameter-height models for several species and heterogeneous crop structures

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Abstract
An examination of the suitability of generalised height-diameter models for growth modelling and augmenting inventory measurements was undertaken. A large database of repeated measurements taken from crop structure experiments since 1963 to the present in Ireland was used. We used a distance independent individual tree height-diameter model to investigate whether inclusion of competition variables can be used to predict variations in height across a wide range of species and silvicultural management regimes. To this end, we stratified the heterogeneous dataset post-hoc into a variety of constituent species, management and silvicultural strata. In addition, we attempted to control for site-specific effects and serial correlation by using a mixed-effects framework in an effort to identify site specific height-diameter variables not explained by the model. The generalised model typically performed well for each species and silvicultural treatment. The most noticeable impact of treatment was observed in plots of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) with differing spacing. The magnitude of inter-plot variability as modelled by a random effect related to the height asymptote varied between species, possibly as a result of inter-species differences in tolerance to variability in environmental growing conditions. Following validation against external data, we show that these generalised models could be used when, in the case of growth modelling for example, it is sometimes necessary to derive individual tree heights from individual tree diameters, perhaps in standard inventory plots where tree height is not measured on every instance that DBH is measured.

Keywords: *Tree height-diameter modelling, individual-tree model, tree competition.*

Introduction

The goal of this study was to find individual-tree, age- and location-independent, species-specific prediction equations that can be used for plots at any stage in their lifecycle under a wide variety of management regimes. Forest inventory datasets usually contain many more measurements of diameter at breast height (DBH, cm) than tree height (H, m). This practice often comes about because it is the DBH distribution which is more variable than the H distribution, and because it may be assumed that the DBH-H relationship can be modelled for the unmeasured heights to be predicted with this model. A common forest inventory approach to DBH-H modelling is to use Chapman-Richard models based on species and plot-specific predictions (Wykoff et al. 1982). However, Chapman-Richards and similar functions are problematic when used as generalised models because the solved function approaches the asymptote too rapidly, particularly when there is a weak relationship between DBH and H in larger trees and across different sites (Temesgen and von Gadow 2004).

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The height-diameter relationship can vary between individual trees in a dataset due to competition, structural allocation variations across different silviculture management types (Cameron and Watson 1999), or variations in site conditions, such as degrees of exposure (Brüchert and Gardiner 2006). Distance independent DBH-H models fitted on the scale of the tree – incorporating information on tree size, inter-tree competition and site differences – have been successfully used to describe variations in height across sites varying in respect of environmental and competitive conditions (Monserud and Sterba 1996, Temesgen and von Gadow 2004, Uzoh and Oliver 2006).

In Ireland, there is an increasing need to develop individual tree growth models and height-diameter functions to facilitate the projection of volume or carbon stock changes using the National Forestry Inventory (NFI 2007). Projections and annual interpolation of tree diameter and height between repeated inventory cycles are particularly relevant for reporting annual carbon stock changes to the United Nations Framework Convention on Climate Change. In this context, height-diameter functions are required to derive height estimates from individual tree diameter increment models, such as those described by Monserud and Sterba (1996).

Temesgen and von Gadow (2004) derived nonlinear regression models that estimate height of individual trees in a stand or plot as a function of DBH, using covariates of competition proxies that are calculated without using the spatial coordinates of trees in the stand or plot (i.e. models that are both age and distance independent). They found that using these competition covariates produced DBH-H models with improved accuracy of prediction, compatibility among the various estimates in a growth and yield model, and maintained projections within reasonable biological limits.

In this study, we used a heterogeneous database pertaining to experimental plots to investigate if the inclusion of these described competition variables can be incorporated to accurately predict, with minimal bias, variations in height across a wide range of species, sites and silvicultural management regimes. For our DBH-H model we followed the approach developed by Temesgen and von Gadow (2004) who described competition using plot density (DENS, trees ha^{-1}), plot basal area (BA, m^2 ha^{-1}), and basal area in larger trees (BAL, m^2 ha^{-1}). (We calculated BAL as the basal area of all trees in the plot whose DBH were greater than the target tree. BAL calculation was made for each measurement occasion, as it was used for DENS and BA.) Unlike Temesgen and von Gadow, we incorporated random site effects as well. The performance of these models was assessed using a randomly sampled, independent and external datasets. The performance of these models in mixed species stands, such as the Sitka spruce[1] and southern provenances of lodgepole pine (*Pinus contorta* Dougl.) mixture on planted blanket peats in Ireland were assessed.

Methods

Datasets for model development and validation

We describe here the relevant aspects of the data in our study. Interested readers will find additional detail pertaining to the datasets in Broad and Lynch (2006a). The data in

[1] The full botanical names and authorities for all species are listed in Table 1.

our study were obtained from Coillte Teoranta's permanent sample plot record system. The dataset contains records from many spacing, respacing and thinning trials (as well as unreplicated sample plots) established during the period 1963 to 2001. The trials were initially established in the 1960s, 1970s and 1980s as replicated experimental designs with consecutive measurements typically made up to 2001. It was common practice to record diameter measurements on an annual basis in the early years of the experiment, with full plot repeated measurements occurring at 3-5 year thinning cycle intervals; thereafter DBH was typically measured for all trees on all measurement occasions. In each permanent sample plot, from 10 to 20 tree heights (depending on plot size) were measured. The experiments were laid out in plots (varying from 0.01 to 0.21 ha) and plot stocking was known at the time of measurement. The species are listed in Table 1.

The permanent sample plot (PSP) trials were set out in ca. 2,900 permanent sample plots with various species and silvicultural treatments, including thinning, spacing and pruning. The dataset used to develop the models described here (the calibration dataset) contained 1170 permanent sample plots. Data from plots were excluded where simultaneous measurements of DBH and H were missing. In addition, all pruning experimental data were excluded from the calibration dataset.

Plots used for thinning and spacing experiments were included in the dataset to which the models were fitted (Tables 2 and 3). The thinning treatments contained in the dataset included (Table 3): no thinning (NTH), no thinning with removal of dead trees (NLT), line thinning -1st cycle only, subsequently selective thinning (LS); selective thinning (SEL); systematic thinning (SYS) and thinning of dominant trees (DOM). Thinning intensity was generally constant across all treatments, using a moderate intensity prior to the advent of the marginal thinning intensity concept introduced

Table 1: *Details of species sampled in the PSP database and the grouping of species or provenances in modelling exercise. Note: both larch species were grouped together.*

Common name	Binomial name	Provenance (if known)
Common alder	*Alnus glutinosa* L.	
Common ash	*Fraxinus excelsior* L.	
Douglas fir	*Pseudotsuga menziesii* (Mirb.) Franco	*Washington and coastal provenances*
Japanese larch	*Larix kaempferi* Fortune ex Gord.	
	Larix decidua Mill.	
Lodgepole pine	*Pinus contorta* Loud.	*South and north coastal provenances*
Monterey pine	*Pinus radiata* D. Don	
Norway spruce	*Picea abies* Karst.	
Pedunculate oak	*Quercus robur* L.	
Scots pine	*Pinus sylvestris* L.	*Scottish*
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	*QCI*

by Bradley et al. (1966) and further developed by Hamilton and Christie (1971). Thinning intensity was also investigated in a small set of experiments (Gallagher 1966, 1969, 1972, Gallagher et al. 1987) wherein heavy, light and moderate thinning were applied, based on the Forestry Commission A-D thinning grades. These thinning grades determined by height or age class, or a relative proportion of basal area at the time of thinning (Gallagher 1969, 1972). The data were not categorised by thinning intensity because these were not documented in the PSP database.

External independent data were used to validate the fitted models. These data came from a cross-sectional sample in 2003 of plots within Coillte production stands (Broad and Lynch 2006a). Such cross-sectional comparisons are particularly useful for assessing inter-plot bias due to a more randomized sampling approach in the validation dataset. These sample plots comprised thinned and un-thinned stands, which had been initially planted at a spacing of 2,500 stems ha^{-1} for coniferous species. External validation data were not available for all species.

Site-to-site variations in the relationship between height and diameter are often well described by inclusion of dependent variables such as aspect, slope or exposure (Uzoh and Oliver 2006). These data are not always captured in sample plot databases, so they cannot be included as dependent variables in the model. These variables were not included in our dataset, so we accounted for plot-to-plot variability with a site variability parameter (Equation 1) in a mixed-effects model (McCulloch et al. 2008).

Table 1 presents the species represented in the PSP database. Table 2 presents summary statistics for the height and diameter at breast height and illustrate the two main features of the repeated sampling structure of the dataset. These tables show the number of repeated measurements on individual trees, which varied from 1 to 18, classified by silvicultural treatment and species. They also showed the degree to which repeated H measurements on sample trees occurred less frequently than their repeated DBH measurement counterparts. Table 3 shows the heterogeneity of experimental treatments present in the dataset, in terms of different thinning intensities and planting spacing distances, for Sitka spruce and lodgepole pine. All the other species were insufficiently represented in the dataset to allow a comparison of different silvicultural regimes.

Table 2: *Summary of the parameterisation dataset, showing range of DBH (cm) and H (m) measurements and summary statistics on counts of series length for consecutive H and DBH measurements on individual trees. Also shown is the number of plots and trees stratified by species.*

Species		**Common ash**	**Norway spruce**	**Douglas fir**	**Monterey pine**	**Sitka spruce**	**Pedunculate oak**	**Japanese larch**	**Lodgepole pine**	**Scots pine**
DBH value (cm)	min	7	2.6	5.3	7.6	4.3	9	7.1	4.4	7.4
	max	15.1	46.7	50.8	38.7	91.2	33.5	38.3	37.7	38.9
	mean	10.3	18.1	15.0	17.3	19.2	17.5	21.9	14.1	17.8
	sd	2.1	6.5	5.9	6.7	8	6.1	5.1	4.3	5.3
DBH (nos. of measurements per tree)	min	2	1	1	5	1	4	1	1	1
	max	3	16	14	6	18	6	6	11	14
	mean	2.79	7.8	3.85	5.9	7.3	5.4	5.5	4.3	9.1
Height value (m)	min	8.5	5	3.8	7.5	3.3	8.8	6.1	1.9	7.7
	max	17.1	26.8	33.6	17.2	47	16.5	26.4	22.5	22.2
	mean	13.2	14.4	12.3	11.3	14.9	13.7	17.2	10.1	15.4
	sd	1.8	3.9	3.9	2.7	5.7	1.8	3.1	2.8	2.3
Height (nos. of measurements per tree)	min	1	1	1	1	1	1	1	1	1
	max	1	3	3	2	6	2	2	3	5
	mean	1	1.1	1.1	1.1	1.2	1.1	1.01	1.1	1.14
Nos. of plots		12	71	98	1	424	1	98	415	18
Nos. of trees		71	1288	1239	10	5631	10	969	4959	417

Table 3: *The number of trees of Sitka spruce and lodgepole pine classified by plot treatment. DOM = dominant trees removed in early thinning, LS = line selection first thinning, Nxx = no thinning at planting spacing of xx metres, NLT = only dead trees are removed, NTH = no thinning, Sxx = selective thinning at planting spacing of xx metres, SEL = selective thinning, SYS = systematic thinning. Explanatory Note: total number of observations exceeds the number of trees (cf. Table 2) because of repeated measurements.*

Treatment	Sitka spruce	Lodgepole pine
DOM	143	0
LS	520	718
N1.22	350	278
N1.83	112	347
N2.44	159	573
N3.05	607	466
N3.67	275	291
NLT	283	41
NTH	2036	1080
S1.22	327	416
S1.83	278	353
S2.44	278	379
S3.05	150	282
SEL	4219	1661
SYS	5976	1580

Nonlinear mixed-effects model

As noted earlier, series of consecutive height measurements for individual trees were much shorter on average (e.g. Series mean ≈ 1) than series of consecutive DBH measurements (Table 2). Such short series made it unfeasible to parameterise the DBH-H models at the level of the individual tree, e.g. to estimate tree-specific coefficients for each tree in the dataset. The parameters of the model equation that were initially fitted to each species in turn is given in Equation 1. This equation corresponds in most respects to Model 7 from Temesgen and von Gadow (2004), but differs slightly on account of the inclusion of a plot-level random effect related to the asymptote.

$$E(H_{ijk} \mid u_i) = (u_i + a + a_{ba}.BA_{ijk} + a_{dens}.DENS_{ijk} + a_{bal}.BAL_{ijk})(1 - \exp(b.DBH_{ijk}^{(c + c_{bal}.BAL_{ijk})}))$$

[1]

In Equation 1, plots, trees and measurement occasions are indexed by *i, j,* and *k,* respectively. *E(.)* is the expectation operator. Equation 1 shows the modelled mean of a conditional Gaussian distribution with mean zero and variance σ^2_e (Table 4). Symbolically, the terms in the model equation are interpreted as *"coefficient.variable"*, i.e. aba is the coefficient of the variable *BA*, and so on. The plot level random effect u_i ~ Gaussian (0, σ^2_u) accounts for correlations between consecutive measurements on the same plot (McCulloch et al. 2008) as well as quantifying inter-plot variability. The model in Equation 1 was selected through a process of model fitting which involved evaluating different model equations for suitability. For example, we tried introducing further parameters to describe correlation and inter-subject variability, i.e. inter-tree variance parameters, but these models were not an improvement on Equation 1.

The *b* Parameter is *a priori* negatively valued (Table 4) so the model equation realistically represents the shape of the empirical DBH-H relationship. The estimated asymptote for trees in the i^{th} plot as DBH tends to infinity, all covariates having been set to zero, is given by $a + u_i$. Models were fitted to each species dataset separately using the algorithms in the SAS NLMIXED procedure (SAS Institute Inc. 2009). The *lattice* library in R v2.10.1 was used to produce the graphical summaries (Sarkar 2008).

Results

The parameter values of the best-fitting models are given in Table 4. The empty cells in Table 4 refer to those parameters that were either not statistically significant (at significance level $\alpha = 0.05$), or that the model did not converge with that parameter included, or that the fitted parameters were inconsistent with the results obtained by Temesgen and von Gadow (2004). (Their results were used as an external benchmark check, which was particularly useful in those cases where convergence was difficult to achieve or the parameter estimates were dubious.) We set the significance level for model selection at $\alpha = 0.05$, but parameters were typically significant below this level. For common ash, the inter-plot variance parameter was not statistically significant, but was retained in the final model because, while its inclusion did not affect the estimated values of the coefficients of the other covariates, we considered it desirable to include inter-plot variability in the estimates of the standard errors of the coefficients.

External validation

External validation data were available for a subset of the species grown in pure plots: Douglas fir, lodgepole pine, Norway spruce, Scots pine, and Sitka spruce. Comparisons of the external validation data and modelled data are shown in Table 5. We also show the empirical distribution of the external validation residuals in Figure 1. Plot size effects were looked for in the external validation residuals but none were found. Residuals plotted against DBH and BAL for all species tested similarly and showed no correlation (data not shown). However, it was evident (Figure 2) that height was overestimated in Sitka spruce stands with a low stocking density (ca. <200 stems ha^{-1} residuals were greater than 5 m). Residuals derived from validation plots with stands of a stocking density below 200 stem ha^{-1} were more likely to have been artefacts of differences in the respective ranges of the DENS variable in the fitting and validation data. In any event, such densities might be considered very atypical in practice.

Mixed plots

RMSE and bias for intimate mixtures of lodgepole pine and Sitka spruce are presented in Table 5. There were few mixture plots present in the dataset and no consecutive height measurements were present in the data for the mixture plots. There were a total of 185 height measurements from nine mixed lodgepole pine and Sitka spruce plots. As such, the results pertaining to mixtures in Table 5 are given in the interest of completeness, rather than as a conclusive or extensive analysis of DBH-H relationships in mixed-species plots.

Management and thinning effects

The dataset consisted of experimental data from many different types of silvicultural and thinning trials (Table 3). Smoothed density estimates of the empirical residual distributions for these trials are shown in Figures 3a and 3b. In general, all experimental types were modelled in an unbiased way, and the residual distributions are symmetrical around zero.

Figures 3a and 3b and Table 5 shows that the lodgepole pine model was more accurate than the Sitka spruce model. The differences in species models were most pronounced in plots where both spacing and selective thinning treatments had been applied and where the spacing levels varied across plots (cf. the S*xx* panels in Figure 3b). There is some evidence that the models for each species performed best at intermediate spacing levels, both in thinned and unthinned plots (Figure 3b). In both lodgepole pine and Sitka spruce, model accuracy was greater in plots where spacing was the only treatment applied, than where spacing and selective treatments were applied (compare rows in Figure 3b).

Table 4: *Estimated model parameters significant at least at $\alpha = 0.05$. Parameter symbols are explained in Equation 1 and related text.*

Species	Parameter								
	a	a_{ba}	a_{dens}	a_{bal}	b	c	c_{bal} [a]	σ^2_u	σ^2_e
Common alder	10.9	0.18	-0.001		-0.13	0.8		2.300	1.01
Common ash	13.3	0.14			-0.18			0.016	0.99
Douglas fir	11.3	0.34	-0.001		-0.07			2.900	1.94
Japanese larch	19.6	0.17	-0.003		-0.07				3.94
Lodgepole pine	11.1	0.11	-0.001		-0.11			3.900	1.04
Monterey pine	19.7			-0.098	-0.06				1.90
Norway spruce	34.5	0.33	-0.003		-0.07	0.6		31.040	1.18
Pedunculate oak	6.3	0.29		0.050	-0.17				0.96
Scots pine	26.2		-0.003		-0.16	0.7		6.700	1.20
Sitka spruce	12.7	0.26	-0.002	-0.003	-0.07			12.100	2.20

[a] This parameter was not significant; however, it was included in the parameter list here because it featured in Equation 1.

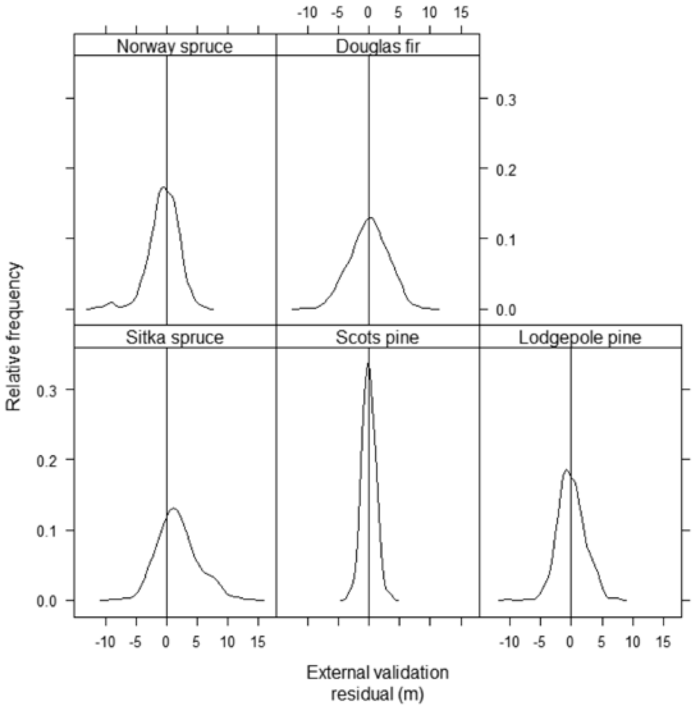

Figure 1: *Smoothed empirical frequency distributions of external validation residuals (Actual height - Predicted height).*

Discussion

Many previously published DBH-H models have not been validated against an independent (external) dataset to investigate the presence of sampling bias in the model parameterisation dataset, as done here. This issue was also highlighted by Broad and Lynch (2006b). Prediction models tend to perform better on data from which they were constructed than on new data. Results are often accepted without sufficient regard to the importance of external validation. The limitations of internal validation are acknolwedged and this work incorporates an external validation to demonstrate the potential generalisability of a diagnostic prediction model to future settings or independently sampled data.

Temesgen and von Gadow (2004) defined generalised DBH-H models as equations that predict tree heights using information on both individual tree DBH and plot or stand level information, such as stand basal area or plot density. Individual-tree distance-independent DBH-H models that do not incorporate information on the plot make the implicit assumption that competition (as measured on the scale of the plot/stand by DENS, and BA, and on the scale of the tree by BAL) does not affect the DBH-H relationship over the lifetime of a tree that is subject to management influences, e.g. spacing and thinning. Plot-specific DBH-H models, that do not condition on plot/stand covariates, are often fitted by a multi-step approach wherein

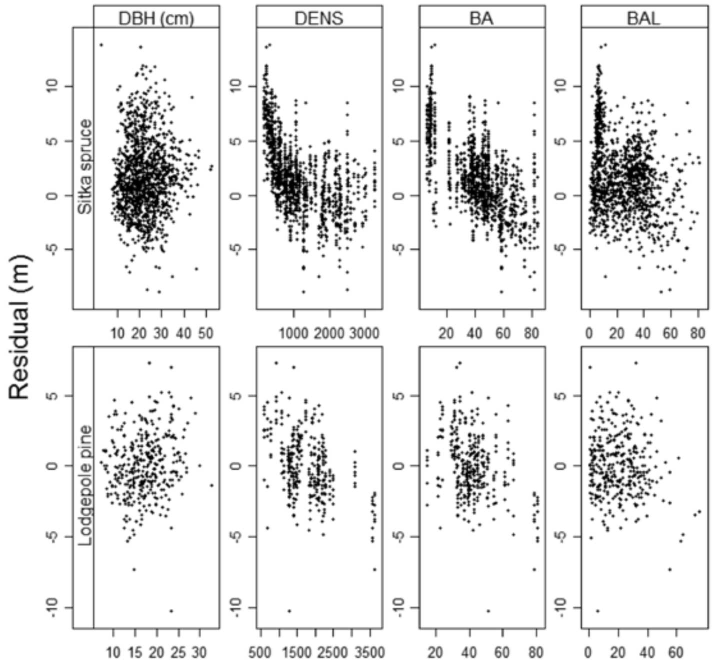

Figure 2: *External validation residuals from the lodgepole pine and Sitka spruce models plotted against a subset of covariates. Note, not all covariates shown here were included in the final models (cf. also Table 4). Scale varies among panels. DENS is plot density (trees ha^{-1}), BA is plot basal area (BA, m^2 ha^{-1}), BAL is basal area in larger trees (BAL, m^2 ha^{-1}).*

separate DBH-H relationships for each plot are fitted. Competition effects are thus at best implicitly described by the variation in each plot-specific fitted parameter.

Generalised models, as defined above, attempt to deal with the broadest response range, so perform better on plots that are near the centre of the sample space dataset rather than plots subject to relatively atypical management conditions. (In fact, this is similar in principle to a standard result in regression modelling, whereby accuracy is maximised at the mean).

Generalised models tend to borrow strength across plots/stands, meaning that issues related to data sparseness on individual plots are mitigated. A plot-specific approach can encounter problems if data for a given plot are so sparse as to not support model fitting. When this occurs in practice, parameters are sometimes pinned at their generalised values, i.e. they are fixed at their value estimated using data from all plots (this approach was used in Ireland's NFI, for example), and the remainder of the parameters are estimated with whatever plot-specific data exist. If there are many such plots in the dataset, this process of estimating parameters plot-by-plot can be tedious; hence the appeal of our approach, which conflates the better aspects of the generalised and plot-specific approaches.

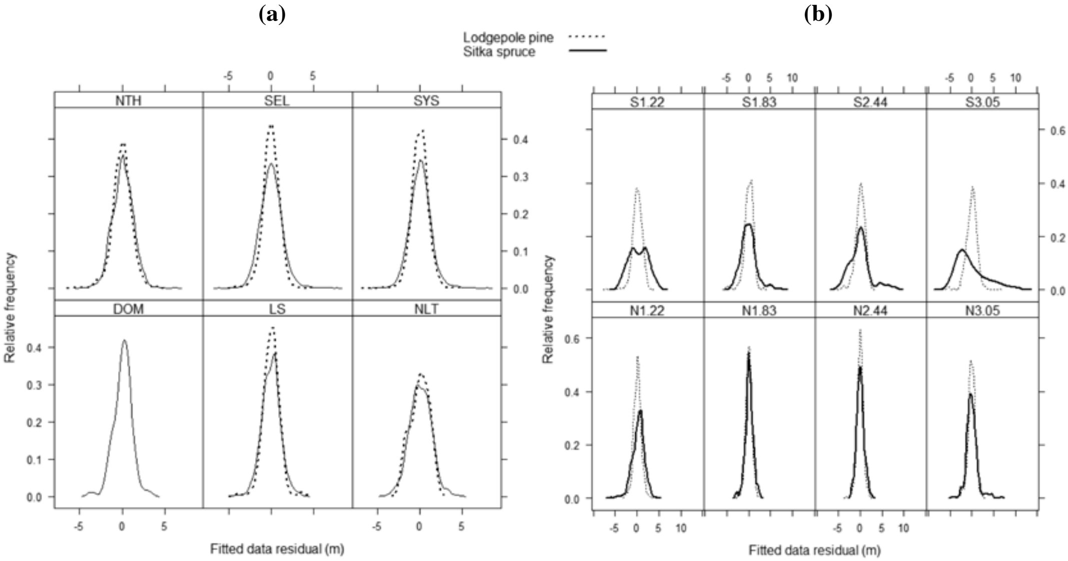

Figure 3: *Classifying fitted-data residuals by experiment type and treatments applied to plots. Only lodgepole pine (broken line) and Sitka spruce (continuous line) are shown because they were the most abundant species in the dataset.*
Data depicted in **(a)** *relates to thinning experiments treatments, where "NTH" denotes unthinned plots, "SEL" denotes selective thinning treatments, "SYS" denotes systematic thinning, "DOM" denotes dominant tree removal, "LS" denotes line and selective thinning plots, and "NLT" denotes removal of dead trees only. See also Table 3.*
Data shown in **(b)** *relates to spacing and thinning experiments. The top row shows selectively thinned plots at an initial spacing of (from left to right) 1.22, 1.83, 2.44 and 3.05 m. The bottom row shows non-thinning treatments at an initial spacing of (from left to right) 1.22, 1.83, 2.44 and 3.05 m.*

We modelled inter-plot variability through a plot-specific random effect related to the asymptote using mixed-model technology (McCulloch et al. 2008). This model feature forms a logical link between generalized and plot-specific models because plot-specific parameters are estimated for plots where sufficient data exist (the u_i terms in Equation 1.). The resulting model equation, if there is an estimated plot-specific effect, predicts for a specific plot. To predict for plots not included in the dataset, or for those plots with insufficient data for plot-specific effect estimation, u_i was set at 0. The mixed model approach used also imposes a common correlation between each measurement on a given plot, and observations on different plots are independent. More complex correlation models (the correlation model, nested within the overall model, cf Equation 1, dealing with how measurements on the same plot or tree are related) did not improve the overall model and the selected final models, therefore fulfil the goal of finding individual-tree, age- and location-independent, prediction equations that can be used for each species for plots at any stage in their lifecycle under a wide variety of management regimes was not fulfilled.

Table 5: *Measures of model performance based on fit to the data and external validation data.*

$$Bias = \sum_{1}^{n} \frac{H_i - \hat{H}_i}{n} \quad and \quad RMSE = \sqrt{\sum_{1}^{n} \frac{(H_i - \hat{H}_i)^2}{n-p}}$$

where $\hat{H}_i$ denotes height (m) predicted by the model, p represents the model dimension and n = the total number of times in a given species dataset, that DBH and H were measured on the same tree on the same measurement occasion. Validation data were not available for all species.

Species	**Fitted data**			**Validation data (where applicable)**		
	Bias/RMSE[a]			**Bias/RMSE**[a]		
	Bias[a]	**RMSE**	**(%)**	**Bias**[a]	**RMSE**	**(%)**
Common alder	-0.00	0.99	-0.06			
Common ash	0.00	1.10	0.18			
Japanese larch	0.01	1.99	0.25			
Lodgepole pine	0.01	0.99	0.90	-0.00	2.30	0.20
Lodgepole pine (in mixture with Sitka spruce)	0.00	1.87	0.13			
Scots pine	0.00	1.11	0.00	-0.04	1.20	0.30
Norway spruce	0.00	1.10	0.30	-0.48	2.50	1.92
Douglas fir	0.10	1.40	3.60	0.01	3.10	0.16
Monterey pine	0.03	1.60	1.90			
Sitka spruce (pure stand)	0.04	1.50	2.70	1.80	3.80	47.00
Sitka spruce (in mixture with lodgepole pine)	-0.01	1.74	0.34			
Pedunculate oak	-0.00	1.20	0.10			

[a] Rounded to two decimal places.

The mixed-effects model framework enables the user to estimate parameters for potentially complex datasets with hierarchical samples and groups. For example, the modelling task might have been accomplished with species-specific random effects models that also incorporated plot-specific effects. Such a nonlinear model with multiple groups and levels of hierarchy is very complex, as is model-fitting and parameter selection, particularly for very large datasets, such as those analysed in this study. Within our framework, the potential for other parameters to vary between plots, i.e. the *b* and *c* parameters in Equation 1, were tested but they did not improve the final model. This suggests that there is overlap between the competition proxy variables, BAL etc., and plot-specific effects that essentially "mop up" residual variability. That random b and c parameters were not statistically significant, given the prior presence of competition variables, is an indication that the competition covariates account for residual inter-plot variability. By extension, the significance of the random asymptote term, indicates a potential shortcoming of those same covariates.

Table 5 shows that RMSE is typically higher for the validation data than the calibration data. The Bias/RMSE ratio increases dramatically for Sitka spruce. This is a due to a combination of reasons, primary among them being the different distribution of plot density values in the calibration and validation datasets. In the validation dataset, the median plot density of Sitka spruce plots is 900 trees ha^{-1}, compared with 1,600 trees ha^{-1} in the calibration dataset. The Bias/RMSE ratio for the upper 50% values in the validation data was only 6%. Therefore, the increase in the ratio was largely due to an inflation in the bias value caused by a mismatch between the calibration and validation data, given that the RMSE for the Sitka spruce validation dataset is of the same order of magnitude as it is for the other species. The susceptibility of the model to this kind of mismatch is illustrated in Figure 2, where external validation residual associations with the covariates are shown for Sitka spruce and lodgepole pine. This phenomenon also partly derives from the inclusion of an asymptote in the model, because mature stands usually contain tall trees at low densities, and it is in that region of the sample space that the fitted curve begins to level off towards the asymptote. This feature is observable in the fitted data also, but at a smaller magnitude than when the model is used "out of sample". We believe that a constant asymptote is necessary in the model so that out-of-sample predictions are robust, in the sense that out-of-sample predictions can potentially become negative without a constant asymptote term.

In the case of larch, the random asymptote model (Equation 1) did not converge. To achieve convergence we could have either omitted the asymptote constant (parameter a) from the model, or omitted the inter-plot variance component (parameter σ^2_u). If the model equation does not have a constant parameter (i.e. parameter a), implausible model estimates of values less than zero can arise. The inter-plot variance component in the final larch model was omitted. For completeness, we note that the estimated inter-plot variance parameter for the model fitted without the constant term (parameter a) was 41.87 (s.e. 6.2). This is large compared to the majority of the estimates of inter-plot variability presented in Table 4. However, the estimated values of this parameter are not directly comparable across different species because they are conditional on different subsets of covariates being included in the models.

The observed level of the inter-plot variation (as measured by the parameter σ^2_u in Table 4) in Norway spruce may be related to species specific responses to exposure (Horgan et al. 2004, Ray et al. 2009) and other factors. Norway spruce is generally considered as very intolerant to exposure (Horgan et al. 2004), typically showing a marked reduction in the slenderness ratio, i.e. the ratio of DBH to H (Wang et al. 1998, Brüchert and Gardiner 2006). By contrast, lodgepole pine is considered to be relatively more tolerant to exposure (Horgan et al. 2004, Ray et al. 2009). In apparent concordance with that relationship, our model estimated relatively lower inter-plot variability for lodgepole pine than for Norway spruce (Table 4).

The mechanism for species-specific variations in the interplot-variability in the relevant DBH-H models is not obvious in our models. Our models do not incorporate quantifiable variables, such as aspect or level of exposure that may reinforce our posited links between species and environment, such as those mentioned in the previous paragraph. However, if additional information describing varying plot and site conditions became available, variables such as site slope, elevation, exposure or aspect could easily be incorporated in the model (e.g. Uzoh and Oliver 2006, Monserud and Sterba 1996) or could be compared with the individual plot-effect estimates in the manner of a residual analysis since, after all, the estimated plot effects are simply residuals related to individual plots.

Conclusions and practical implications

We fitted a generalised DBH – H model incorporating covariates pertaining to tree size and competition to a dataset that encompassed a wide range of silvicultural management conditions and tree species. We post-stratified the dataset into its constituent species and experiment-type groupings, examined the model fit using an external validation dataset, and found that the generalised model performed well in the vast majority of cases. The incorporation of variables that describe site-specific conditions and how such models might relate to the relatively more empirical mixed model approach implemented here may be investigated in the future.

The practical implications of the study were:

- The generalised DBH-H models presented here can be used in forest inventories to derive height, if not available, based on DBH measurements. The derived height measurements can assist in more accurate determination of single tree volumes, top height or taper equations.
- The advantage of using single tree models, which are calibrated across a range of spacing and thinning treatments, is that one model can be used. In contrast, traditional stand-based models, which are parameterised for different silvicultural treatments (e.g. GROWFOR), use separate models for thinning and non-thinning scenarios.
- The Irish national GHG reporting system, CARBWARE, uses the described model to derive height increment based on DBH growth models. The same modeling approach could be used for timber forecasting at the single tree level. Timber projections at the single tree level provide a more accurate estimation of timber assortment distribution, when compared to stand-based models.

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Ireland's Native woodlands: A summary based on The National Survey of Native Woodlands

John Cross[a*]

Abstract
A summary of the national survey of native woodlands, undertaken between 2003 and 2008, along with a preliminary survey of possible ancient and long-established woodland, is presented. The total area of native woodland was ca. 85,000 ha, the woodlands were unevenly distributed geographically and individual woodlands were small (average size 6.6 ha) and highly fragmented. They showed considerable diversity in terms of species complement and vegetation type and the woods were classified into 4 major types – sessile oak, ash, alder and birch – and 22 sub-types. Native woodlands showed considerable structural variation, both vertical and horizontal, depending principally on the canopy species, management and grazing regime. Regeneration of most species was generally poor. Many woods are currently unmanaged and there was little timber of merchantable quality. A conservation assessment found that the highest scoring sites were concentrated in the west and in Wicklow. Invasive alien species, especially sycamore, beech, rhododendron and cherry laurel, and inappropriate grazing regimes (under- or over-grazing) were found to be the main threat. The importance and value of our native woodlands is discussed and the desirability of combining conservation with timber production is highlighted.

Keywords: *Survey, native woodlands, classification, characteristics.*

Introduction

The expansion of native Irish forests following the last glaciation and the subsequent decline to their nadir in the early part of the 20th century is well documented (e.g. Mitchell and Ryan 1997, Feehan 2005). The remnants of these original forests that may have survived, or those which sprung up following the devastation caused by the famines of the 19th century, have undoubtedly coloured the perception of our native woodlands ever since and it is probably true to say that many landowners and foresters still considered them to be of little value, economically or otherwise.

In recent decades, however, their importance for biodiversity, conservation and general environmental benefit ("ecosystem services") has been increasingly recognised. Nonetheless, apart from a few detailed studies, e.g. the Killarney Woods (Kelly 1981), hazel-ash woods (Kelly and Kirby 1982), wetland woods (Kelly and Iremonger 1997, Cross and Kelly 2003), knowledge of their distribution, extent and character remained poor. Further, it was recognised that existing classifications (e.g. White and Doyle 1982, Fossitt 2000, Cross 2005) were based on limited data and were therefore incomplete and possibly inappropriate.

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To rectify this situation, the National Parks and Wildlife Service, in association with the Forest Service, undertook a detailed, systematic National Survey of Native Woodlands (hereafter referred to as the Survey) between 2003 and 2008 (Perrin et al. 2009). This Survey was partly driven by requirements under the EU Habitats Directive, under which several woodland types (oak, alluvial, yew and bog woodland) are designated for protection within Special Areas of Conservation (SACs). Further, with the introduction of the Native Woodland Scheme by the Forest Service in 2000, a better understanding of the resource was also required.

The Survey examined not just at the woodland flora, structure, physical characteristics and conservation value of the woodlands, but also collected information of relevance to foresters and landowners with an interest in their economic value, e.g. tree size, timber quality. The information gathered represents the most detailed and comprehensive study of native Irish woodlands ever undertaken. This paper summarises the results of these surveys while also drawing on other relevant literature.

Methods

The basis for the survey was a modified version of The Forest Inventory Planning System (FIPS) (Gallagher et al. 2001), a GIS system based on a combination of satellite imagery (1993-1997) and aerial photographs (1995) that mapped and provided attribute data on wooded areas in the State (Higgins et al. 2004). This was augmented with information from the Coillte database, the Soil Parent Material Classification Project and the National Parks and Wildlife Service database of digitised habitat maps of areas designated for conservation. The accuracy of the combined data was checked against the 2000 series of colour aerial photographs. Additional data was obtained from literature and personal communication with foresters, ecologists, etc. and information on the size of areas was updated from the National Forest Inventory (Anon. 2007), published towards the end of the survey.

A subjective stratified sampling procedure was used to ensure that a broad range of woodland types were sampled and to include certain types of woodland which might have been missed in a purely randomised approach. Sites selected included:

- woodlands within designated areas and large blocks of woodland, for which little or no data existed;
- isolated woodlands in largely unwooded landscapes;
- valley woodlands;
- woodlands marked on the 1st edition Ordnance Survey Maps (taken as dating from 1830).

Woodlands, which upon examination were dominated by non-native trees or shrubs, were excluded. The number of sites selected per county was proportional to the total area of native woodland present in each county. To qualify for selection, stands had to be >1 ha in area, >40 m wide (>20 m along lakeshores and riverbanks), have a canopy height >5 m (>4 m in wetland woods), a canopy cover >30% and consist of >50% native species. For the purposes of this survey Scots pine[1] was not

[1] Because of the large number of species referenced in this paper, only the common names are given in the text. See Tables 4 (woody) and 5 (non-woody) in Appendix 1 for lists of the botanical names of the species.

considered to be a native species, although its extinction in Ireland is relatively recent and it is often held to be semi-native. See Roche et al. (2009) for a detailed discussion on its status

In each site a general survey was conducted in which the following were recorded:

- location in relation to topography (e.g. upper slope, valley floor), altitude, slope and aspect; area and boundaries (based on FIPS);
- soil type;
- presence of water-bodies;
- vascular plants and bryophytes (excluding epiphytes);
- surface cover for each strata using the DAFOR scale (dominant, abundant, frequent, occasional, rare);
- vegetation communities based on Fossitt (2000);
- dead wood;
- land use, including grazing regime and past and present management;
- tree regeneration;
- alien invasive species; artefacts, e.g. walls, ditches, old buildings, etc.

Within each site one or more 10 × 10 quadrats or relevés was sampled in which the following data were recorded:

- 10 figure grid reference;
- all species of vascular plants and bryophytes growing on the ground with their percentage cover (using the Domin scale);
- number of seedlings/saplings of all tree species; tree height, DBH (if >7 cm) and crown position (to allow for variations in tree density the plot size was augmented where necessary to enable 30 trees per quadrat to be recorded);
- presence of merchantable timber (DBH >40 cm) including the estimated commercial log length and the presence of stem defects.

In addition, five soil samples were taken in each relevé, bulked and analysed for pH, % loss on ignition and total phosphorus (mg g^{-1}). The relevé data were subjected to a series of statistical analyses to classify the vegetation. A conservation and threat score was calculated for each site. Further details of the methodology are given in Higgins et al. (2004) and Perrin et al. (2008).

In addition to the sites selected from the FIPS database, supplementary relevé data were obtained from several other sources, principally van der Sleesen and Poole (2002) covering eastern County Offaly and Browne et al. (2000) covering parts of 3 riverine Special Areas of Conservation (the lower Barrow, Upper Shannon and Unshin). In total, the survey included 1,320 sites and 1,667 relevés.

The results are published in six volumes (Perrin et al. 2008). In addition, a database was compiled with details of each site and relevé surveyed, including GIS information of the areas of native woodlands indicating the location of the sites surveyed. Following the main survey, a provisional inventory of ancient and long-established woodlands was also undertaken, based on documentary evidence supplemented with field data from the main survey and some additional survey work. Results are presented in Perrin and Daly (2010) and recorded in a GIS and database. The results of both surveys are also available on the National Parks and Wildlife Service website (NPWS 2012).

Results

The area and distribution of native woodlands

It is difficult to obtain precise figures for the area of native woodland. According to the most recent figures from the National Forest Inventory (Anon. 2007) there are ca. 130,000 ha of land under native species, representing ca. 2% of the land area of the country. However, this figure includes small stands and narrow strips within conifer plantations which cannot be considered as native woodland. John Redmond, Forest Service (pers. comm.), estimates that there are ca. 85,000 ha of woodland with a canopy consisting of >80% native species, including hazel and willow scrub, representing 1.25% of the land surface. In addition, there are 36,000 ha of mixed conifers and native trees in which the latter constitute between 20-80% of the cover. The total area under native species which may be considered as native woodland is therefore likely to be considerably higher than 85,000 ha.

Native woodlands occur scattered throughout the country but there is a concentration in some upland areas, e.g. in the mountain valleys of Wicklow, Waterford, Kerry and Donegal, and also in central Clare. Low hazel woodland is particularly extensive over the shallow limestone of Clare and Galway and extensive birch woodland has developed in parts of the midlands. The least wooded counties are Carlow, Louth and Dublin while the blanket bogs of north-west Mayo and Connemara are also largely devoid of native woodlands. In the more fertile parts of the country, native woodland is typically confined to agriculturally less attractive areas, such as esker ridges or valley sides, as well as occurring around former demesnes where they were often planted for shelter, game cover or for landscaping (Figure 1).

The average size of the 1,320 woodlands surveyed was 6.6 ha. 50% were less than 6 ha in area, only 3.3% exceeded 50 ha and very few exceeded 100 ha. However, these figures are based on the National Forest Inventory which is now more than 15 years old. Many native woodlands have been fragmented through interplanting with non-native species in the past. In the intervening period non-native stands have been removed in a number of places and the cleared areas left to regenerate naturally or have been planted with native species, thus considerably expanding the area of individual woodlands. Nonetheless, by international standards Irish native woodlands are very small and fragmented.

Species of native woodlands

A total of 1,083 species were recorded in the Survey of which 175 were exotic species. Of the remaining native species, 27 were ferns and horsetails, 277 were bryophytes and 604 flowering plants. (For a list of vascular plants mentioned in the text see Appendix 1). About 80% of all species occurred in fewer than 10% of the sites. The bryophytes were under-recorded, partly because some may have been overlooked on account of their size but also because a systematic recording of epiphytes did not form part of the survey's intent. Of the exotic species, the majority occurred only in very small numbers or were localised.

Of native species, the most frequently occurring was bramble, found in 98% of all sites, closely followed by ivy (96%). The most frequently occurring trees were hawthorn, ash and holly, occurring in 92%, 90% and 85% of sites, respectively. Of

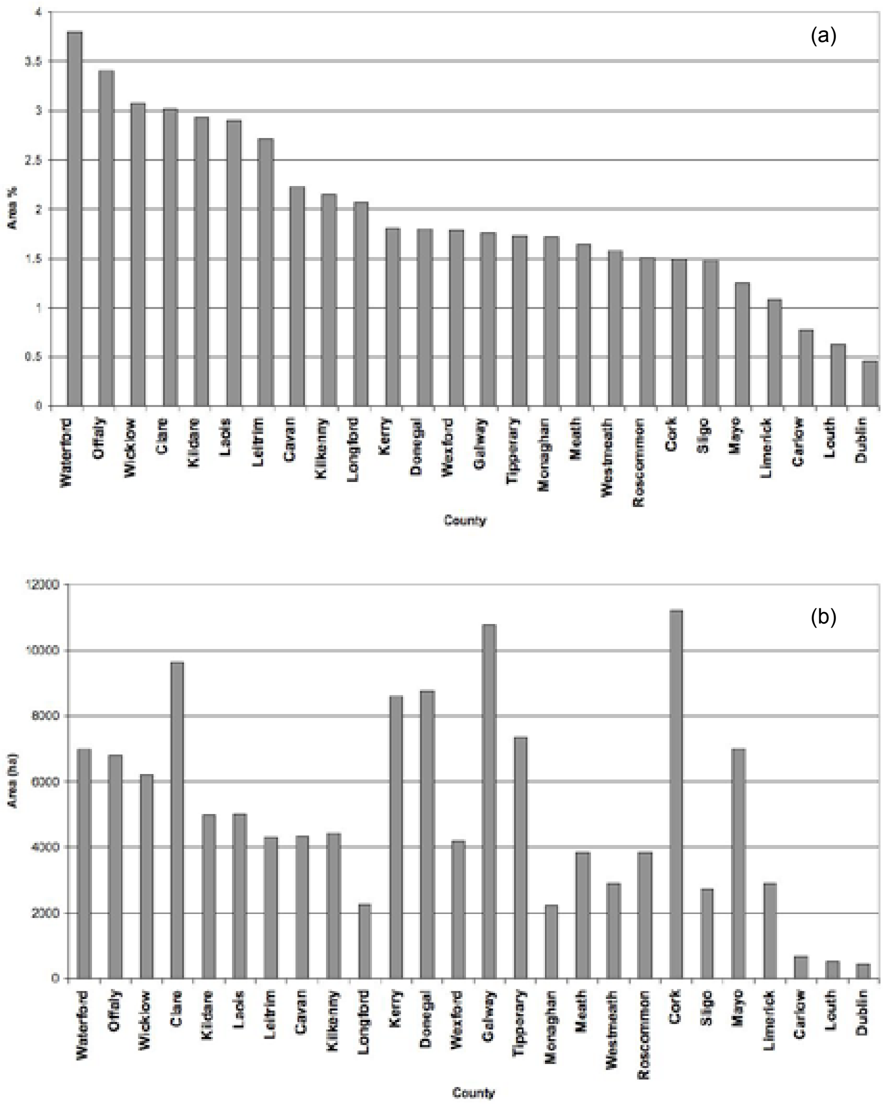

Figure 1: *Area (a) and density (b) of native woodland per county.*

the herb layer, broad buckler-fern, herb-Robert, creeping buttercup and meadowsweet were the most frequent species (Table 1). Some vernal species, e.g. lesser celandine, were probably under-recorded when sites were surveyed late in the season. Rare species, such as wood melick and narrow-leaved helleborine, were very localised and for that reason may have been overlooked in the general survey: they appeared to be confined to ancient woodlands.

Table 1: *The 20 most abundant vascular plants occurring in native woodlands.*

Common name	Latin name	% occurrence
Bramble	*Rubus fruticosus*	98.0
Ivy	*Hedera helix*	96.6
Hawthorn	*Crataegus monogyna*	92.3
Ash	*Fraxinus excelsior*	90.2
Broad buckler-fern	*Dryopteris dilatata*	89.8
Holly	*Ilex aquifolium*	85.4
Honeysuckle	*Lonicera periclymenum*	84.5
Herb-Robert	*Geranium robertianum*	83.2
Grey willow	*Salix atrocinerea*	78.2
Creeping buttercup	*Ranunculus repens*	73.6
Common birch	*Betula pubescens*	72.4
Sycamore	*Acer pseudoplatanus*	72.1
Meadowsweet	*Filipendula ulmaria*	72.1
Wood avens	*Geum urbanum*	71.6
Nettle	*Urtica dioica*	71.5
Hazel	*Corylus avellana*	70.2
Scaly male-fern	*Dryopteris affinis*	69.6
Beech	*Fagus sylvatica*	68.6
Enchanter's nightshade	*Circaea lutetiana*	65.5
Violet	*Viola* spp.	65.4

Types of native woodland

Based on analyses of the 1,667 relevés, native woodlands were classified into 4 principal types: sessile oak-woodrush, ash-ivy, alder-meadowsweet and birch-purple moor-grass woodlands. These reflect two major soil gradients: acidic-basic and wet-dry. Each type was sub-divided into numerous sub-types giving a total of 22 sub-types, two of which are sufficiently distinctive to be considered as separate, but minor, types – yew and willow woodland. In addition, hazel woodland in the west of the country may be a distinct type, although closely related floristically to ash woodlands. Brief descriptions are given below and in Table 2. More detailed descriptions, along with affinities to other classifications, can be found in Cross et al. (2010).

<u>Sessile oak-woodrush woodland</u>

Sessile oak woodlands occurred on acidic, well-drained mineral soils, mostly podzols with a pH typically ca. 4.5 - 4.9, in upland areas, frequently on hillsides and valley sides. They were characterised by a dominance of oak, mostly sessile oak but sometimes pedunculate oak or the hybrid (Q. × *rosacea*), typically forming a canopy ca. 18 m high, although individual trees exceeded 30 m. Downy birch was the principal associated species, other trees playing a minor role. Holly formed the shrub layer but rhododendron was often abundant, especially in areas of high rainfall. On more fertile soils, for example at the base of slopes and beside streams, ash and hazel may occur along with other species characteristic of ash-ivy woodlands.

A dwarf shrub layer of bilberry and sometimes ling heather was typically present. These often formed a mosaic with the herb layer which was usually species-poor and often dominated by woodrush. Ferns were abundant and honeysuckle and ivy were constant. Some of these woodlands, especially in the west and in sheltered humid sites elsewhere, were noted for the richness and luxuriance of the mosses, liverworts and lichens.

Ash-ivy woodland

Ash woodland was the most extensive and widespread woodland type in Ireland occurring throughout the country on base-rich, usually calcareous soils, with a pH mostly >6.0, although occasionally <5.0. Ash woodlands display considerable diversity, occurring on a range of soil types, including deep, moist, fertile loams; dry, shallow sandy or gravelly soils; gleys subject to periodic waterlogging and excessively drained rendzinas over limestone pavements.

The canopy, which exceeded 20 m on deep soils, was typically dominated by ash but often contained a considerable amount of pedunculate oak. Typically, ash woods had a much richer vascular flora than sessile oak woods with a variety of trees species present, usually in small amounts. The shrub layer was usually dominated by hazel, often with hawthorn and a variety of other species. The vernal flora was typically well developed and colourful and could be dominated by bluebell. Later in the summer, ferns and enchanter's nightshade were often prominent. Dense tangles of bramble also occurred. The bryophyte flora, while diverse and sometimes species-rich, was usually more poorly developed than in oak woodlands.

Low-growing woodland in which hazel was the principal component of the canopy, was an important variant of ash woodlands. It was particularly well developed on the shallow limestones of Clare and Galway, although also occurring elsewhere. While this may form an early successional sere to ash woodland, it may belong to the so-called Atlantic hazel woods, which have only recently been described (Coppins and Coppins 2010) and which may be "climax" woodland. These woodlands are characterised by a suite of bryophytes and lichens that by and large do not occur on more recently developed stands.

Alder-meadowsweet woodland

Alder woods were widespread throughout the country on wet, poorly drained, gleyed, mineral or peaty soils with an average pH ca. 6.2. Like ash woods, alder woods showed considerable variation.

Although alder was constantly present, it was not always dominant, with other species, such as ash or grey willow often forming the canopy or sometimes co-dominant. The shrub layer consisted mostly of grey willow, although locally hawthorn could be abundant. A variety of other trees and shrubs were also be present at times, although typically in small quantities. The characteristically thin canopy and the variety of micro-habitats, such as wet depressions, drier hummocks and tree bases, resulted in a species-rich and sometimes luxuriant herb layer. The bryophyte layer, while relatively diverse, was typically scanty.

Birch-purple moor-grass woodlands

Birch woodlands were widespread throughout the country, principally on acidic substrates, pH 4.3-5.0. Their main concentration was on undifferentiated, dried-out peat of cutaway raised bogs in the midlands but they also occurred locally elsewhere on mineral soils. Birch is the only major tree species in Ireland which can tolerate wet, acidic conditions and birch stands were also found on wet oligotrophic peat on both high bog and cutaway. Downy birch was overwhelmingly the dominant species in these woodlands and was by far the commonest species in the country as a whole. Silver birch, although widespread, was relatively uncommon: of 13,220 birch stems measured within relevés only 17 were of silver birch.

Characteristically, birch woods are species-poor and birch was overwhelmingly dominant, other tree species playing very much a secondary role, although locally Scots pine could be an important constituent. The herb layer was typically poorly developed and characteristically dominated by a few species, e.g. bracken. In contrast, the moss layer may be well developed, although again not species-rich. A very distinctive community dominated by *Sphagnum* species could occur on both high bog and cutaway, forming so-called "bog woodlands". Locally, where there was ground water influence, the flora was richer with elements of alder woodlands.

Yew-carnation sedge woodland

These were distinctive and rare and confined to limestone outcrops in the southwest of the country. The overwhelming dominance of yew, with some ash, beech and both native oak species resulted in very species-poor and poorly developed shrub and herb layers. The moss layer in contrast was often luxuriant but dominated by just a few species.

Willow-nettle woodland

Willow woods occurred principally on nutrient-rich alluvium along the banks of slow-flowing lowland rivers. They were subject to frequent inundation and their roots were almost permanently waterlogged. Several species of tree willow dominated, including the native grey willow, but the most prominent species were white willow, crack willow and the common osier, which were probably introduced several centuries ago, principally for basket making. These woodlands were characterised by a very distinctive and luxuriant flora of tall herbs.

Alluvial woodland

Alluvial woodland is a generic term for a complex of ash, alder and willow woodlands subject to periodic flooding alongside rivers and on lake shores. It also includes spring-fed systems. Alluvial woodland is specifically protected as a priority habitat under the EU Habitats directive.

Table 2: *Frequency (%) and basal area of the principal tree species.*

Species	% of trees	% of basal area
Downy birch	21.3	13.6
Ash	18.5	15.4
Hazel	10.1	4.9
Grey willow	8.0	6.1
Alder	7.2	7.9
Sessile oak	6.8	18.3
Holly	6.0	2.6
Pedunculate oak	4.9	14.1

Ancient and long-established woodlands

The first comprehensive maps of Ireland (the Down and Civil Surveys) were drawn in the 1650s and after this date planting of new woodland was widely encouraged. Ancient woodlands are therefore defined in Ireland as areas which have been wooded since 1660. Long established woodlands are sites which have been continuously wooded since the 1st edition Ordnance Survey maps but for which no documentary evidence has been found that they date back to 1660 (Perrin and Daly 2010). However, any woodland which appears on the 1st edition Ordnance Survey maps should be considered as potentially ancient, unless there is evidence to the contrary. Woodlands that have developed since the 1st edition Ordnance Survey maps are called recent woodlands. Rackham (2005) summarised the demise of Irish woodlands, which he considered "a series of disasters" and concluded that "little ancient woodland survives".

For a given size, ancient and long-established woodlands had significantly more vascular plant species than recent woodlands. They also tended to have a suite of species which were less common or rarer in younger woods, e.g. bugle, wood anemone, red campion (Perrin and Daly 2010). Further research is required to ascertain whether they contain other species of significance, e.g. invertebrates, lichens. They did not necessarily contain ancient trees and in fact were often characterised by the lack of old trees because they had been intensively managed in the past. Rackham (2003) contends that many ancient woodlands in England have survived only because they were of economic value in the past.

These woods are particularly valuable for their biological as well as cultural importance as they may contain plant and animal species and communities which are confined to, and indeed dependent upon, the continuous presence of woodland cover throughout the historical period. In this respect they are irreplaceable and should be considered as living national monuments and managed accordingly. The area of ancient or long-established woodlands is unknown but, based on an examination of the 1,320 sites in the Survey, is at least 16,674 ha. There are undoubtedly other sites which have not yet been documented: these may still be native woodland, or have been subsumed into other broadleaved or conifer plantations. A provisional list of putative ancient and long-established woodlands is given in Perrin and Daly (2010).

Woodland structure

Woodland structure may be considered in terms of vertical structure, i.e. the canopy, shrub, herb and bryophyte layers, and horizontal structure, i.e. varying density of trees, clearings etc. Age and size of the stand and of individual trees and shrubs, as well as past management and current landuse all determine the structure. Even-aged stands appear to be the rule rather than the exception, even in unmanaged forests (Peterken 1993), and this is related to periods of regeneration, which are often related to certain events, restricted in time e.g. felling, storms.

Typically, there are 4 or 5 layers: the canopy, shrub, dwarf-shrub (principally in oak and birch woodlands), herb (or field) and the moss (or ground) layers. In some woods a sub-canopy may be present and occasional emergents may occur, especially in low-growing woodlands. One or more layers may be absent or poorly developed for a variety of reasons, e.g. age of the stand, heavy grazing. Horizontal variation in structure is influenced by factors such as changes in soil type, wind throw, crown damage and felling. Ride-lines, clearings, streams, pools, etc. provide additional variation and important habitat for edge species and flight-lines for invertebrates, birds and bats.

Of 47,416 trees recorded in the Survey, the most frequently occurring species were birch, ash and hazel. Sessile oak and pedunculate oak were much less frequent (Table 3). However, in terms of basal area the most important trees were sessile oak, ash, pedunculate oak and birch. Alder was more frequent than the oak species but the basal area was much less. These figures reflect both the size and abundance of the species, oak tending to have lower stocking rates but forming larger trees, whereas birch and alder tend to have higher stocking rates but are smaller trees. This is illustrated in the frequency curves (Figure 2) which also suggest a much lower turnover of the oaks, although it also reflects the longevity of these species. The large number of small diameter ash reflects the high rate of regeneration.

Regeneration

Most native Irish tree species require a high light climate to regenerate successfully, but different species display different strategies and some are shade tolerant. Oak (Kelly 2002) and birch species are both light demanding. In contrast, ash seedlings can survive for many years under relatively low light levels. This may be because the buds of seedlings open a few weeks before the buds of trees in the upper canopy allowing assimilation to occur before the light climate declines. Subsequently, they take advantage of gaps in the canopy by growing rapidly into these gaps (Wardle 1959). Rowan seedlings also tolerate relatively low light levels (Pigott 1983). Both holly (Peterken and Lloyd 1967) and yew (Perrin 2002, Perrin et al. 2006) are shade tolerant.

Of the major forest trees, ash seedlings (<25 cm) were by far the most abundant, sometimes carpeting the forest floor, and accounting for 75% of all recorded regeneration. Furthermore, in terms of the ratio of seedlings per adult stem, ash (79:1) was by far the highest. However, very few survived to reach 2 m in height (saplings). In contrast, the ratio of holly seedlings per adult stem was only 9:1, but 10% survived to exceed 2 m. Regeneration of oak species was poor – only 2.1% and 0.4% of all

Table 3: *Summary of the main woodland types and their principal species. Names in italics indicate the most common species.*

Woodland type	Characteristic species			
	Canopy	Shrub layer	Dwarf shrub layer	Field layer
Sessile oak – woodrush:	*Sessile oak*, *Common birch*, Ash.	*Holly, Rowan, Rhododendron*, Hazel.	*Bilberry*, Ling heather.	*Woodrush, Hard fern, Broad buckler-fern*, Wood sorrel Hay-scented buckler fern, Bracken, Honeysuckle, Ivy.
Ash-ivy:	*Ash, Pedunculate oak*, Birch, Cherry, Grey willow, Crab apple, Beech, Sycamore, Alder.	*Hazel, Hawthorn*, Holly, Spindle, Guelder rose.	Usually absent.	*Bluebell, Bramble, False wood-brome,* Anemone, Violet, Lesser celandine, Primrose, Enchanter's nightshade, Herb-Robert, Lady fern, Soft shield fern.
Alder-meadowsweet:	*Alder*, Grey willow, Ash, Downy birch.	*Grey willow,* Hawthorn, Hazel, Guelder rose.	Absent.	*Meadowsweet, Creeping bent, Creeping buttercup*, Remote sedge, Herb-Robert, Enchanter's nightshade, Water mint, Marsh bedstraw, Yellow flag.
Birch-purple moor-grass:	*Downy birch,* Rowan, Scots pine.	Grey willow.	Bilberry.	*Bramble, Bracken,* Purple moor-grass.
Yew-carnation sedge:	*Yew*, Ash, Beech, Oak spp.	*Hazel*.	Absent.	Carnation sedge, Bramble, Violet, Barren strawberry, False wood-brome.
Willow-nettle:	White willow, Crack willow, Common osier.	Grey willow.	Absent.	*Meadowsweet, Nettle, Reed canary-grass*, Water dropwort, Bindweed, Angelica, Marsh marigold.

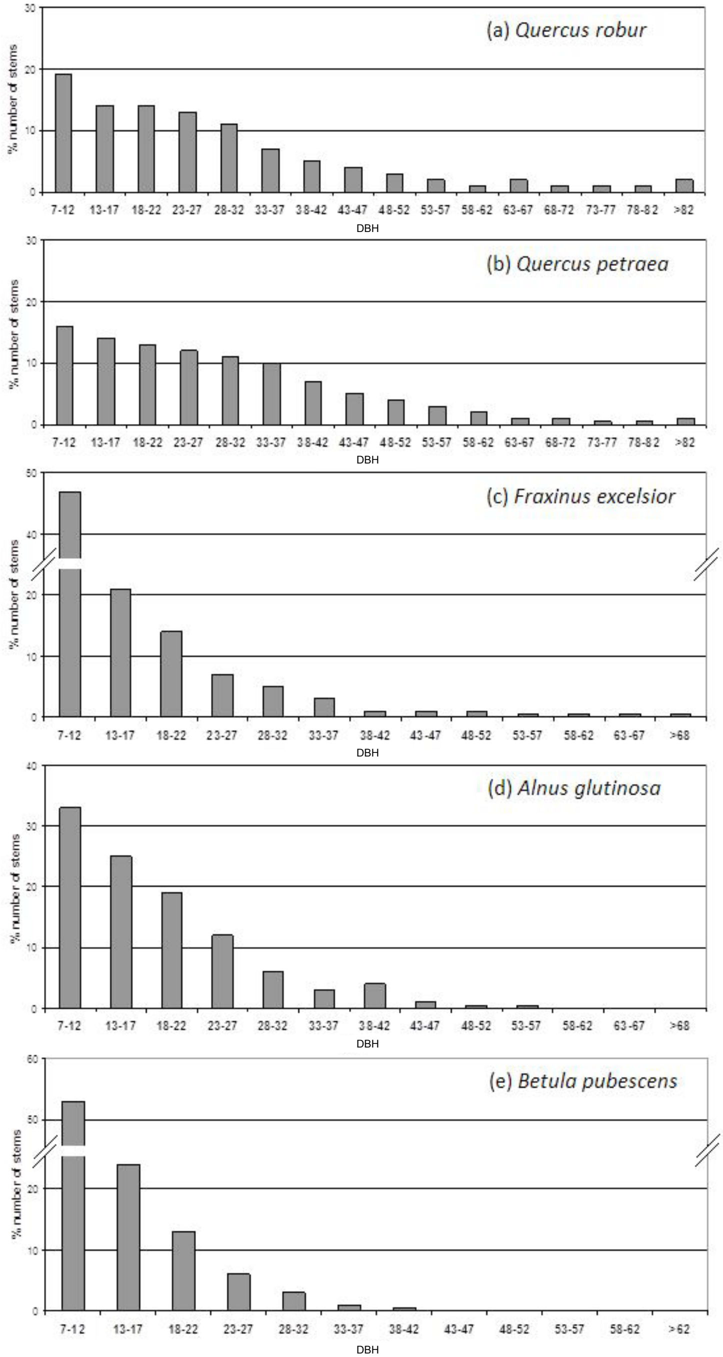

Figure 2: *Tree size (DBH) frequency distributions for the principal canopy-forming species*.

regeneration for sessile and pedunculate oak, respectively - and the ratio of seedlings per adult stem was also low (6.5 and 2, respectively). Large numbers of oak seedlings are occasionally recorded both in time and space but only a minority survive more than a few years (Kelly 2002).

In contrast to the situation under a canopy, regeneration of native species in light gaps and clearings can be prolific, especially in the absence of grazing and if the herb layer is poorly developed. Early successional species such as birch and grey willow, often accompanied by ash, can regenerate in large numbers, along with smaller quantities of holly, rowan, hazel, alder (on moist soils) and oak, to form dense stands within a few years.

Timber

The Survey highlighted the absence of good quality timber in most woods. Data collected from ca. 67,900 stems showed that <4% reached or exceeded a DBH of ≥40 cm, the size considered to be of merchantable quality for saw-log. Of the total number of trees recorded, just over 12% were oak (both species), of which 21% were of merchantable size accounting for 60% of all stems of merchantable size. Ash constituted 16% of the total number of trees but only 3% were of merchantable size, representing 12% of all stems of merchantable size. Of the other native trees, only very small numbers were ≥40 cm DBH. Non-native trees, mostly beech and sycamore, represented 6% of the total number of stems measured but over 14% were of merchantable size.

Of the stems of merchantable size only 60% were of merchantable quality, due to a number of defects, principally forking (29%), heavy branching (21.5%), bending (17%) and heavy ivy (15.5%). Eighty-nine percent of the oak stems of merchantable size had lengths of merchantable quality compared with only ca. 10% each for ash, birch and alder.

Deadwood

Deadwood is an integral and essential element of any woodland and is a means by which nutrients are recycled. It is also a habitat for a great variety of organisms, being particularly important for certain bryophytes, lichens and saproxylic invertebrates and fungi. Different types of deadwood provide different niches, each with its own suite of associated organisms. Several categories were recognised: fine woody debris (<5 cm diameter); coarse woody debris (>5 cm diameter); standing dead (branches and/or trunks); uprooted trees/root plates (which may not always be dead); snags/snapped trees, all of which could be in different states of decay.

The amount of deadwood within Irish woodlands is poorly documented. The Survey undertook a rough assessment using a scale of abundance (abundant, frequent, occasional, rare). Results show that fine woody debris and coarse woody debris were frequent to occasional in the majority of sites, standing dead/damaged wood was relatively uncommon and snags and snapped trees were rare or absent. Sweeney et al. (2010) found that the mean volume of dead logs in a small sample of oak forests was ca. 20.5 m^3 ha^{-1}, and in ash forests 27 m^3 ha^{-1}. Ninety percent of logs were <20 cm diameter. Mean snag density in the same stands was 92 ha^{-1} for oak and 87 ha^{-1} for ash, most being <20 cm diameter. These relatively high figures may reflect the high rate of competition between stems within the woodlands surveyed.

Invasive alien plant species

Very few woodlands, even if remote, were entirely free of alien plants in one or more layers of the woodland. Abundance varied from scattered individuals to dense, sometimes dominant stands. The Survey found that the most frequently occurring alien tree species were sycamore, which occurred in 72% of sites, beech (69%) and Sitka spruce (25%). Seedlings and saplings of sycamore were much more common than beech. The abundance of the two broadleaf species reflected both their wide ecological tolerance to soil pH and their widespread planting. Both species could be invasive and had major detrimental effects on native flora and fauna through the dense shade that they cast. However, they were not universally problematic; sycamore was more vigorous in ash woods on moist, base-rich soils and beech in both ash and oak forests on drier base-rich to acidic sites.

The most abundant shrubs were rhododendron (23% of sites), cherry laurel (20%) and snowberry (12%). Rhododendron was particularly invasive in sessile oak woods where its dense shade severely affected the native flora and fauna, especially in more humid areas, as well as causing difficulties for management (e.g. Cross 1982, 2002). Cherry laurel was more common on base-rich soils which are generally less suitable for rhododendron. It was less invasive than rhododendron but observations suggest that in recent years regeneration by seed appears to be increasing. Other species which were locally invasive, and potentially problematic, include red-osier dogwood and Himalayan balsam in wetland woods (see also Kelly and Iremonger 1997), Japanese knotweed, Himalayan honeysuckle, wild clematis, and some conifers (e.g. western hemlock) (Figure 3).

It should be noted that native woodlands which were severely infested with alien plant species were not surveyed. Consequently the above figures may underestimate the number, area and severity of sites affected and may reflect a bias in site selection. This may partly explain the apparent greater frequency of sycamore than rhododendron, although the former has a much greater ecological tolerance, occurring on a wider range of soil types.

Grazing

Grazing is an integral part of the ecology of natural woodlands. At low levels it facilitates structural diversity, encourages high levels of biodiversity in the field and ground layers, maintains open areas and promotes regeneration by reducing competition from certain herbs (Perrin et al. 2006, 2011). Where grazing pressure is too high the woodland structure is damaged (e.g. loss of shrub layer), regeneration of native species is reduced and there is a decline in herbaceous species, although the cover and diversity of bryophytes may increase (Kelly 2000). Unpalatable species, e.g. rhododendron, beech, however, are often favoured (e.g. Cross 2002). If the grazing pressure is very low or absent the field layer may become dominated by a few aggressive species, e.g. bramble, to the detriment of other species growth and regeneration of trees (Perrin et al. 2006, 2011). Open areas, which are important

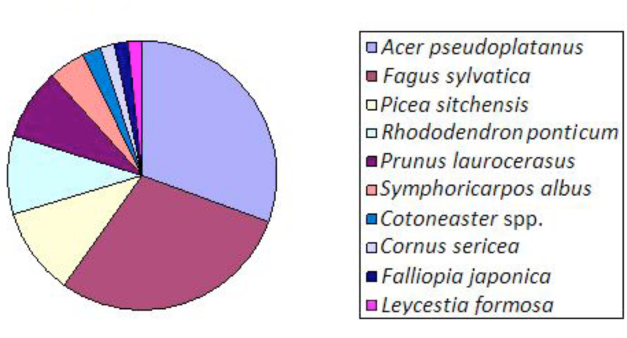

Figure 3: *Frequency (%) of invasive alien trees and shrubs at surveyed sites.*

for certain invertebrates and birds, may be invaded by trees and shrubs or become dominated by dense stands of bramble or bracken.

The Survey found that overgrazing was not a national problem in a geographic sense but was confined to a relatively few specific localities, particularly certain unenclosed upland areas where there were large numbers of deer, e.g. Wicklow Mountains, south Kerry and east Galway. Sheep and feral goats were more common in upland than in lowland areas but were recorded much less frequently than deer. In the lowlands the principal grazers were cattle, with the highest incidence of grazing recorded in Co. Clare. In many lowland areas enclosed woods were considered to be undergrazed and overgrazing was found to be limited to a few woodlands where domestic stock were overwintered.

There is, however, considerable evidence that in recent years, and especially since the Survey was completed, that the population of deer has increased in many parts of the country (Purser et al. 2009). Damage to native woodlands from deer grazing is now more widespread and severe and particularly acute in parts of Wicklow and Kerry. This could become an even greater problem if muntjac deer, recently reported from a few locations, should become well established.

Management

Signs of former management are widespread and common (Figure 4). Many older sites are highly modified, although they may not have been managed for many years and have reverted to a relatively natural appearance, e.g. Killarney Woods (Bradshaw and Quirk 2001), Wicklow Woods (Jones 1986, Carey 2009). There was a high frequency of old stems of non-native broadleaves (36% of sites) and conifers (34%) throughout the country. Old woodlands tended to have been managed more than young woodlands, some of which showed no signs of management, e.g. in inaccessible sites or on cutaway bog. Most woodlands showed some signs of felling, even if only occasional stems have been cut or pollarded. Mature coppice was recorded from 18% of sites and appears to be widespread, although it was not always easy to differentiate systematic coppicing regimes (as is known to have been practiced in Wicklow; Carey 2009) from a single felling event. Recent felling was recorded in 12% of sites, including woodland clearance for housing. Felling of ash for hurleys, both legal and illegal, was recorded in some woodlands, particularly in counties where hurling is strongest!

One of the most striking features of the woodlands surveyed was that few appeared to be actively managed currently, although in 20% of sites there was evidence of recent planting. However, certain management activities, e.g. clearance of cherry laurel, can be quickly masked by new growth and it is possible that management activities had been overlooked.

Of non-forestry related management, livestock grazing was the most common landuse, being recorded in ca. 39% of sites. Cattle were the most common grazers, principally in the lowlands, followed by sheep and, much less frequently, horses. Amenity was also a common landuse, both casual and actively encouraged, as evidenced by the creation and maintenance of paths.

Conservation

The Survey undertook a semi-quantitative assessment of 1,312 sites for which data were available using 15 criteria, including size, species diversity, structural diversity, habitat diversity, age of woodland, etc., to evaluate their conservation quality. Emphasis was placed on the naturalness of sites, i.e. characteristics regarded as indicative of more natural aspects of native woodland, such as high (native) species diversity, high structural diversity.

Higher scoring sites tended to be relatively large, ancient or long-established woodlands with structural and species diversity and often contained more than one woodland type. They showed either a pronounced westerly distribution or occurred in Wicklow. Low scoring sites were generally uniform and species-poor with a tendency

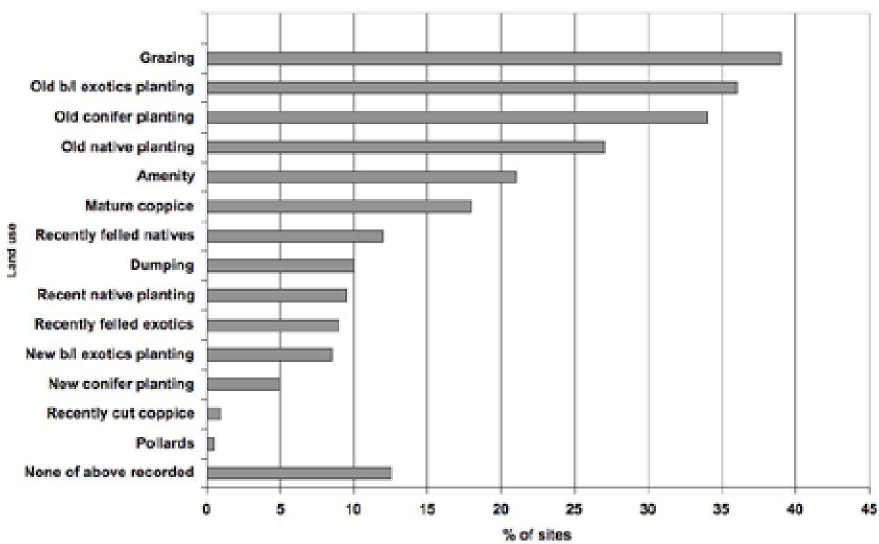

Figure 4: *Frequency (%) of observed management and landuse at surveyed sites.*

to occur in the east or intensively agricultural parts of the country. All the highest scoring sites were found within nature reserves, Special Areas of Conservation (SACs), National Parks or proposed Natural Heritage Areas (pNHAs).

The conservation scores must, however, be interpreted with some caution as all woodlands were compared, irrespective of type. In particular, they tended to undervalue alluvial woodland sites, which were not assessed as a separate category, and yew and bog (birch) woodlands, which were small and naturally species-poor but of very high conservation value by virtue of their rarity.

A threat score was also calculated, which took account of grazing pressure, presence of exotic and invasive species and damaging management activities. The principal threat came from invasive alien plants and over-grazing, but no site was considered under severe threat and over 17% of sites had no threat. However, as previously noted, the prior selection process, by which sites with a high density of invasive alien species were excluded, may have underestimated this threat.

Discussion and conclusions

This paper summarises the very large amount of information collected in the course of the National Survey of Native Woodlands in Ireland. The Survey provides the most comprehensive overview of the native woodland resource to date and serves as a basis for future reappraisal of its significance, role and function.

The Survey highlights the fragmented nature of the resource, the very small area of ancient or long-established woodlands remaining, and from a forestry point of view, their very limited value for timber production. On the positive side, it identifies the remarkable diversity which is present in terms of woodland types and plant species-richness, which is likely to be reflected in the diversity of other organisms, e.g. invertebrates (Cotton 2005), fungi (Dowding 2005). This information will provide a foundation on which to develop strategies for both future forestry and conservation policies, landuses which are not mutually exclusive but can be mutually beneficial.

Native woodlands are part of our natural and cultural heritage and their European significance should not be overlooked (Cross 2006). Their importance for biodiversity is recognised by the fact that over 30,000 ha receive some form of protection under either national or EU legislation. In addition, they play an important role in ecosystem services, e.g. soil protection, hydrological regulation, carbon sequestration, climate change mitigation etc., and they are an important genetic resource. Properly managed, they can also be a valuable and renewable source of raw material, e.g. construction timber, fuel biomass, veneer timber.

It is neither practical nor desirable for all our stands of native woodland to be designated for conservation/biodiversity, although their inherent value should not be ignored. Many sites within SACs and pNHAs can, and perhaps should, be managed for timber production, although conservation should always take precedence over timber production within known ancient woodlands. The challenge is how to maximise both environmental benefit and economic return. The value of native woodlands for timber production is still often overlooked, despite a considerable volume of literature on the subject, e.g. Bulfin (1992), Joyce et al. (1998), Gallagher (2005) and Little and Cross (2006). This may be because existing woodlands are perceived as a greater management challenge than the creation of new plantations.

Appropriate management and restoration of neglected native woods can result in profitable, small-diameter timber, as demonstrated by the success of Coed Cymru (2011) in Wales. The quality of larger timber and the woodland as a whole can be gradually improved while, at the same time, the conservation value of the woods and the benefit to the general environment can be enhanced. While some landowners in Ireland are already managing their native woodlands for both timber production and biodiversity, the development of a similar organisation in Ireland would greatly promote the value of native woodlands and assist landowners to maximise both the economic and conservation benefits of their woodlands.

Practical implications

- While native Irish woodlands cover only a small area and are highly fragmented, they nonetheless contain a diversity of woodland types and structure and a great wealth of species, all of which require careful management to maintain their conservation value.
- Ancient woodlands, i.e. those sites which have been wooded since at least 1660, are particularly important for their biological and cultural significance and should be very carefully managed.
- Invasive alien species and over- or under-grazing are the principal management issues which need to be addressed.
- Few native woodlands are currently managed for timber production and they contain little good quality timber. Properly managed, native woodlands could provide both environmental benefits (e.g. biodiversity, ecosystem services) and an economic return to landowners.

Acknowledgements

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Appendix 1
List of common and Latin names (after Preston et al. (2002)) of plants mentioned in the text, divided between woody species (Table 4) and non-woody species (Table 5).

Table 5: *Woody species*.

Common name	Botanical name
Alder	*Alnus glutinosa* (L.) *Gaertn*.
Ash	*Fraxinus excelsior* L.
Beech	*Fagus sylvatica* L.
Birch - downy	*Betula pubescens* Ehrh.
Birch - silver	*B. pendula* Roth
Cherry - bird	*Prunus padus* L.
Cherry - wild	*Prunus avium* L.
Cherry laurel	*Prunus laurocerasus* L.
Common osier	*Salix viminalis* L.
Crab apple	*Malus sylvestris* Miller
Elm	*Ulmus glabra* L.
Guelder rose	*Viburnum opulus* L.
Hawthorn	*Crataegus monogyna* L.
Hazel	*Corylus avellana* L.
Holly	*Ilex aquifolium* L.
Honeysuckle	*Lonicera periclymenum* L.
Ivy	*Hedera helix* L.
Ling heather	*Calluna vulgaris* (L.) Hull
Oak - sessile	*Quercus petraea* (Matt.) Liebl.
Oak- pedunculate	*Q. robur* L.
Red-osier dogwood	*Cornus sericea* L.
Rhododendron	*Rhododendron ponticum* L.
Rowan	*Sorbus aucuparia* L.
Scots pine	*Pinus sylvestris* L.
Sitka spruce	*Picea sitchensis (*Bong)
Snowberry	*Symphoricarpos alba* Duh
Spindle	*Euonymus europaeus* L.
Sycamore	*Acer pseudoplatanus* L.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Whitebeam	*Sorbus hibernica* E.F. Warburg
Wild clematis	*Clematis vitalbe* L.

Willow - almond	*Salix triandra* L.
Willow - crack	*S. fragilis* L.
Willow - goat	*S. caprea* L.
Willow - grey	*S. atrocinerea* L.
Willow - white	*S. alba* L.

Table 6: *Non-woody species.*

Common name	**Botanical name**
Angelica	*Angelica sylvestris*
Bilberry	*Vaccinium myrtillus*
Bindweed	*Calystegia sepium*
Bluebell	*Hyacinthoides non-scripta*
Bracken	*Pteridium aquilinum*
Bramble	*Rubus fruticosus*
Broad buckler-fern	*Dryopteris dilatata*
Bugle	*Ajuga reptans*
Carnation sedge	*Carex flacca*
Creeping bent	*Agrostis stolonifera*
Creeping buttercup	*Ranunculus repens*
Enchanter's nightshade	*Circaea lutetiana*
False wood-brome	*Brachypodium sylvaticum*
Filmy fern	*Hymenophyllum species*
Hard fern	*Blechnum spicant*
Hay-scented buckler-fern	*Dryopteris aemula*
Herb-Robert	*Geranium robertianum*
Himalayan balsam	*Impatiens glandulifera*
Himalayan honeysuckle	*Leycesteria formosum*
Japanese knotweed	*Fallopia japonica*
Lady fern	*Athyrium filix-femina*
Lesser celandine	*Ranunculus ficaria*
Marsh bedstraw	*Galium palustre*
Marsh marigold	*Caltha palustris*
Meadowsweet	*Filipendula ulmaria*
Narrow-leaved helleborine	*Cephelanthera longifolia*
Nettle	*Urtica dioica*
Primrose	*Primula vulgaris*

Purple moor-grass	*Molinia caerulea*
Red campion	*Silene dioica*
Reed canary-grass	*Phalaris arundinacea*
Remote sedge	*Carex remota*
Soft shield fern	*Polystichum setiferum*
Violet	*Viola riviniana/reichenbachiana*
Water dropwort	*Oenanthe crocata*
Water mint	*Mentha aquatica*
Wood anemone	*Anemone nemorosa*
Wood avens	*Geum urbanum*
Wood melick	*Melica uniflora*
Wood sorrel	*Oxalis acetosella*
Woodrush	*Luzula sylvatica*
Yellow flag	*Iris pseudacorus*

The development of a taper model and a diameter at breast height to total height model to predict user defined roundwood assortment volumes in Sitka spruce first thinning plantations in Ireland

Enda Coates[a*], Tom Kent[a] and Michael Pedini[a]

Abstract

A taper equation and a diameter at breast height (DBH) to total height model were developed for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) trees of first thinning stage in Ireland. The use of the models may be of benefit to forest practitioners who require information on the volumes of specific assortments prior to harvest, particularly where the practitioners wish to define the dimensions of these assortments themselves, such as in the wood energy sector. The models could be implemented into a tool for practitioners, once further field trials are undertaken to estimate the degree to which errors are propagated. To develop the models, data were collected from 433 trees on five private forest sites in Ireland. The Kozak (2004) variable exponent taper equation was parameterised using the data. This taper equation utilises total height as an input, and therefore an estimate of total height per tree was required. A Chapman Richards equation was parameterised to predict total height from DBH. Using the equations together, the volumes of 90 sample trees were predicted, and then compared to actual measurements. The equations predicted the full stem length volume with a standard error estimate of 0.0098 m^3 per tree, and a bias of 0.00003 m^3 per tree.

Keywords: *Kozak's taper model, Chapman Richards height model, forest energy, volume estimation.*

Introduction

The National Forest Inventory (NFI) (2007) identified 233,000 ha of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) under 20 years of age in Ireland and further identified that 120,000 ha of this species was in private ownership. Philips (2011) estimated that total annual thinning area will more than double from the current 22,800 ha to 49,400 ha by 2028, as this young forest resource comes into production. He noted that the majority of the increase in annual roundwood production over the coming years will come from the private sector forests and warned that without first thinning, roundwood production will be much lower than predicted. Similarly, forecast models predict that the demand for wood biomass for energy will increase from 1.589 million $m^3\ yr^{-1}$ in 2011, to 3.084 million m^3 in 2020 (CRDG 2011). It was noted that expansion of the wood energy sector may cause competition for the panel board industry seeking wood fibre, so supply and demand will remain finely balanced.

Standard forest thinning control and pre-sale measurement practices estimate standing tree volume to merchantable timber height. Merchantable timber height is

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where the stem tapers below 7 cm diameter (Matthews and Mackie 2006). The actual volume, as cut by a harvesting machine, will differ from this estimate in two ways. The volume will be less when cutting to a specified length, as only full log lengths can be processed. For example, a stem of 4.5 m merchantable volume height will only produce one 3 m length log, the other 1.5 m will be discarded. The volume will be greater than the estimate when using a full stem assortment, as the full stem includes the material above the height where the stems taper below 7 cm diameter (Keogh 1987). In the first thinning of a Sitka spruce stand, an average of 26% additional biomass was recovered in energywood harvesting, where the whole stem was processed into variable lengths, compared to harvesting standard roundwood assortments (Kent et al. 2011).

Research into the taper of forest trees is documented as far back as 1913 (Stoehr 1955), but perhaps some of the earliest functions constructed for prediction purposes was from work carried out in British Colombia (Newnham 1958). By 1969, it was well recognised that a total volume per ha estimate was no longer sufficient for harvest planning. It was necessary to be able to estimate the volume of specific log sizes and also the number of such logs that could be produced from a growing forest. At first, it was thought that additional upper stem measurements would need to be taken during inventory fieldwork. However, after the development and testing of a number of taper equations, it was shown that stem modelling could produce accurate results without the need for upper stem measurements (Kozak et al. 1969). Since then taper functions have been used across the globe for predicting upper stem diameters and log volumes. They are frequently used in inventory and growth modelling projection systems due to their flexibility and ability to estimate multi product volumes (Trincado and Burkhart 2006). More recently, Fonweban et al. (2011) developed taper equations for Scots pine (*Pinus sylvestris* L.) and Sitka spruce in Northern Britain. In Ireland, Nieuwenhuis et al. (2005) used a taper equation as part of a value-maximisation decision-support tool in a sawmill production chain.

Taper is defined as "the rate of narrowing in diameter in relation to increase in height of a given shape" (Gray 1956). Different taper equations use different shapes to describe a tree's stem: the lower section near the butt being a frustum of a neiloid, the middle section being a frustum of a paraboloid, and the top section being a paraboloid (Avery and Burkhart 1983). Many of the more complex taper models use a number of polynomial functions joined together to recreate the stem form (Trincado and Burkhart 2006). Some models will fit specific tree species and conditions better than others, so it is beneficial to test a number of models with a particular type of forest dataset to find the best fit, as per Walters and Hann (1986). According to Kozak (2004), taper equations are superior to volume equations, as volume equations only estimate total or merchantable volume, whereas taper equations provide estimates of: "i) diameter at any point along the stem, ii) total stem volume, iii) merchantable volume to any top diameter, iv) merchantable height to any top diameter, v) individual volumes for logs of any length at any height from the ground."

The aim of this study was to develop a system of models which can be used to predict stem volumes in Sitka spruce first thinnings. This may be of particular benefit to private forest managers in the planning phase of thinning operations. The private forest sector has not yet developed long-term contracts to supply small roundwood to end-user defined specifications. The models could potentially assist the manager in optimising the value of thinnings through market selection of the timber before harvesting. The models could be used by both state and private sectors to simulate the harvest volume from user-specified assortment dimensions. Harvesting methods could then be selected that best match the optimal return from the forest.

Materials and methods

Data collection

The data were collected on five sites; three sites in the west of Ireland, one in the midlands and one in the south (Table 1). The ages of the stands ranged from 13 to 20 years, and were even-aged Sitka spruce monocultures, except for one site where the spruce was intimately mixed with Japanese larch (*Larix kaempferi* L.). The Japanese larch was not used in this study. In order to evaluate the performance of the models, some of the data were partitioned to be used for independent validation. This method of evaluation is described by Kozak and Smith (1993), and was used in a similar context in a study by Nieuwenhuis et al. (1999) where a taper model and diameter at breast height (DBH) to height model were also developed for volume estimation.

Table 1 details the site descriptions and the number of sample trees measured during this study. The models were developed with the data from sites 1-4, and the data from site 5 was used for validation. In total, 433 sample trees were felled and measured. Approximately 30 trees were selected per line in each stand. The lines were picked at random from each site. The sample trees were felled by chainsaw and measured for total height and DBH. The stem was marked at 1 m intervals from the base to the tip, and the diameter at the mid-diameter point of each interval recorded to the nearest cm (rounded down). Figure 1 displays a scatterplot of data showing relative height versus relative diameter. The horizontal line of data points appearing at a relative diameter value of 1.0 is the result of every tree being measured for its DBH, as relative diameter was taken as the quotient between the upper stem diameter and the DBH of the tree. The distortion apparent above 1.0 relative diameter is the result of the buttressing of the stems close to the ground.

Table 1: *Characteristics of the sampling sites.*

Site	Location	Area (ha)	Age (years)	Stocking (stems ha^{-1})	Mean DBH (cm)	Top height (m)	No. of sample trees
1	Abbyfeale, Co. Limerick	10	20	2,191	17	13.5	90
2	Ballybofey, Co. Donegal	21	13	2,455	14	11.2	75
3	Bweeng, Co. Cork	10	17	2,252	13	11.1	88
4	Toormakeady, Co. Sligo	14	16	2,624	13	10.9	90
5	Woodberry, Co. Galway	27	17	2,199	15	12.3	90

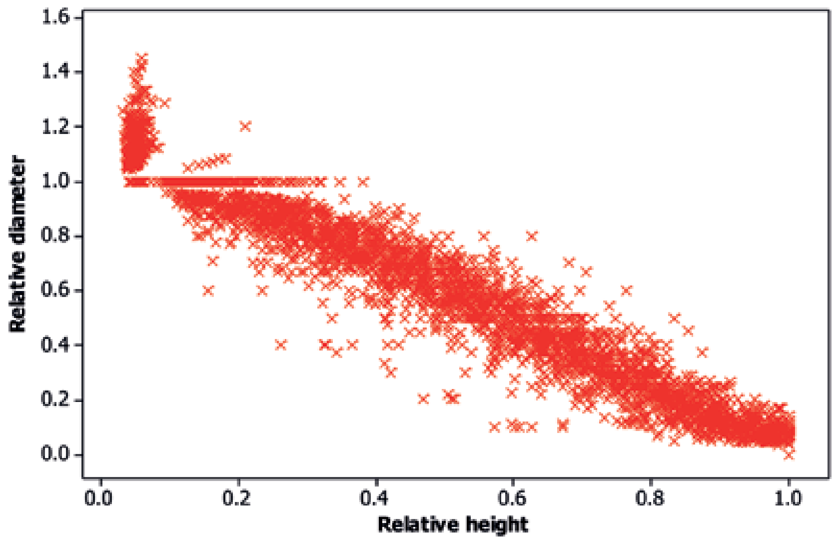

Figure 1: *Scatter plot of relative diameter (the upper stem diameter divided by the DBH of the tree) versus relative height (the height of the upper stem diameter divided by total height of the tree) of the data collected.*

Taper equation

A taper equation formulated by Kozak (2004) was parameterised using the data collected. Kozak's taper equation was chosen as it has been used extensively in modelling the taper of plantation trees, including studies based in Ireland and the UK (Fonweban et al. 2011, Nieuwenhuis et al. 1999). The Minitab 16 statistical software package (Minitab Inc. 2010) was used to fit the equation using non-linear regression. Kozak's taper equation is given as Equation 1:

$$d=\beta_1 DBH^{\beta_2} x^{[\beta_3 z^2+\beta_4 \ln(z+0.001)+\beta_5(\frac{DBH}{ht})]} \qquad (1)$$

where d is predicted diameter (cm), x is $\frac{1-\sqrt{z}}{1-\sqrt{p}}$, p = point of inflection is $\frac{1.3}{ht}$, ht is total tree height (m), h is height along the stem at predicted diameter (m), z is $\frac{h}{ht}$ is relative height of predicted diameter, DBH is diameter at breast height (cm), β_1 to β_5 are the parameters to be estimated from the regression analysis (Fonweban et al. 2011, Kozak 2004).

DBH to total height equations

As the taper equation utilises total height as an input, an estimate of total height per tree was required. A Chapman Richards DBH to total height model, as cited by Kershaw et al. (2008), was parameterised using the data. Recently, this Chapman Richards function has been used to predict tree height by the NFI (2007). The NFI (2007) fitted this model to Sitka spruce data taken from plots throughout Ireland. In this study the model was developed in the same way: the model was parameterised using the data from sites 1 to 4. When using the model for predicting the total height of individual trees in a plot, the height and DBH of a sample height tree was used to localise the model to this plot. This was deemed as a necessary inclusion as the DBH to height relationship is not homogenous across different site conditions (Diéguez -Aranda et al. 2006). It should be noted that the NFI (2007) locked β_3 at 0.7 in 84% of the cases in which the Chapman Richards model was used. This methodology was also tested in this study. The Chapman Richards model is given as:

$$ht = 1.3 + \beta_1(1 - e^{-\beta_2 dbh})^{\frac{1}{\beta_3}} \tag{2}$$

where ht = total height of the tree, and β_1 to β_3 are the parameters to be estimated from the regression analysis (Kershaw et al. 2008).

Model evaluation

The models were evaluated for their ability to fit the data sets by assessing the root mean squared error (RMSE) from the output of the regression analysis, as per Fonbewan (2011). As recommended by Kozak and Smith (1993), the models were evaluated for their prediction abilities and were compared to validation data sets for bias and standard error estimates (SEE).

Average bias was defined as:

$$\text{Mean Bias} = \frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)}{n} \tag{3}$$

where Y_i is actual observation, $\hat{Y}_i$ is predicted value of the actual observation, and n the number of observations.

The standard error estimate was given as:

$$\text{Standard Error Estimate} = \sqrt{\frac{\sum_{i=1}^{n}(Y_i - \hat{Y}_i)^2}{n-k}} \tag{4}$$

where k is the number of estimated parameters (Jiang et al. 2005).

Results and discussion

Taper model

Table 2 details the parameter estimates for the taper model, and the associated 95% confidence interval for each estimate. The RMSE was estimated at 1.001 cm. Kozak's model was fitted to Sitka spruce in the UK with a RMSE of 0.983 cm (Fonweban et al. 2011), which is similar to the 1.001cm in this study. Figure 2 displays the residuals of the fit. Figure 3 displays a histogram of the residuals.

Table 2: *Coefficients and uncertainty ranges from regression analysis to parameterise.*

Parameter	Estimate	95% Confidence Interval	
β_1	1.14369	(1.10540,	1.18341)
β_2	1.00093	(0.98956,	1.01231)
β_3	-0.15975	(-0.20687,	-0.11306)
β_4	1.30694	(1.23812,	1.37624)
β_5	0.06093	(0.03453,	0.08752)

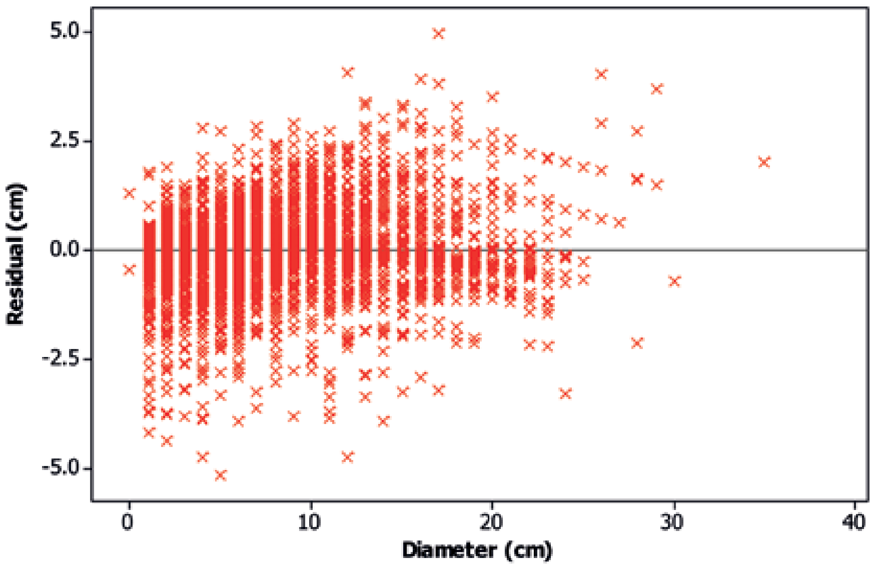

Figure 2: *Residuals from the fit of the taper equation to the dataset.*

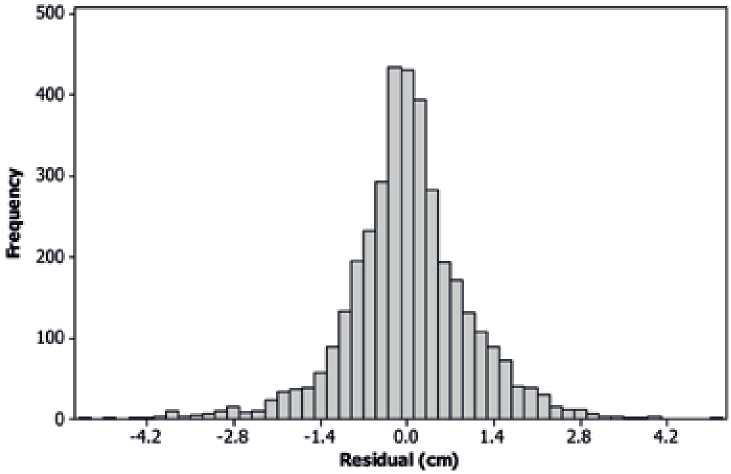

Figure 3: *Histogram showing the frequency distribution of the residuals from the fit of the taper equation to the dataset.*

To assess the model's prediction abilities, the model was used to estimate diameters at 1 m intervals from the validation data. The validation data comprised 90 trees, giving a total of 979 predictions. The results were then compared to the actual measured stem diameters of these trees as observed in the field. The input data to the models were the DBH and total height as measured for each tree. Table 3 provides the SEE and mean bias. The data are grouped by each 10% increment of relative height to enable comparisons along the stem. The overall SEE is 0.85 cm, and the overall bias is -0.06 cm.

Table 3: *Prediction statistics for the parameterised taper model using the validation data.*

Relative height %	n	SEE (cm)	Bias (cm)
0-10	99	1.07	0.09
10-20	168	0.53	-0.38
20-30	90	0.86	-0.13
30-40	93	0.83	0.08
40-50	91	0.83	0.38
50-60	88	0.84	0.34
60-70	90	0.83	-0.08
70-80	90	0.73	-0.22
80-90	89	0.60	-0.38
90-100	81	0.46	-0.10
Overall	979	0.85	-0.06

DBH to total height model

The parameter estimates and associated confidence intervals of the DBH to total height model are detailed in Table 4. Figure 4 displays the fitted model line through the data set, and Figure 5 presents a histogram of the residuals.

Table 4: *Parameter estimates for the DBH to total height model.*

Parameter	Estimate	95% Confidence Interval	
β_1	10.8599	(10.4688,	11.2950)
β_2	0.1558	(0.1427,	0.1703)
β_3	0.7000		(locked)

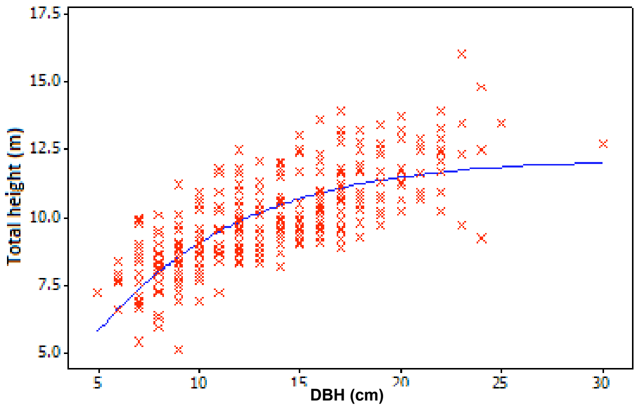

Figure 4: *Data with fitted DBH to total height model line.*

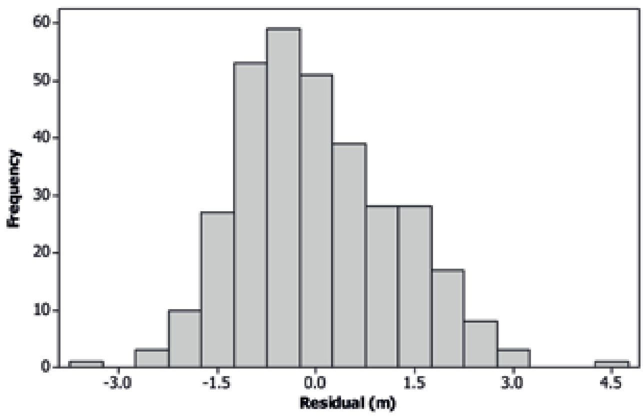

Figure 5: *Histogram of the fit residuals from the DBH to total height model.*

Table 5: *Statistics for parameterised DBH to height model using validation data.*

Plot	n	Top height (m)	QMDBH[a] (cm)	Dominant DBH (cm)	Model statistics	
					SEE (m)	Bias (m)
1	31	13.6	12.1	21	0.99	-0.67
2	29	9.7	13.0	22	0.60	0.91
3	30	13.7	15.6	23	0.92	-0.26

[a] QMDBH = quadratic mean DBH.

The validation data were collected from three plots at a single site at a single site (Table 5). The model was localised to each plot through non-linear regression as described in the methodology section.

The parameterised Chapman Richards model was localised by adjusting β_1. This was done using a sample height measurement and the associated DBH of the sample height tree. Ideally, a number of trees would be measured for height and used for the adjustment. However, it was found that there were two benefits to using only one tree:

i) it required no additional measurement;

ii) the adjusted parameter of β_1 could be defined mathematically without non-linear regression.

As the majority of forest managers may not have access to non-linear regression tools, it was important that the models could be used as a stand-alone entity that could be implemented into a simple spread-sheet software package. As all other terms in the equation are known, it was possible to rewrite the equation to solve for β_1. This gives the model the ability to localise to a plot by entering to the equation the values of sample tree height (sH) and DBH of the sample height tree (DBH_{sH}) measured in the stand, as outlined below:

$$\text{If total height (ht)}=1.3+\beta_1\times(1-e^{-0.155793DBH})^{\frac{1}{0.7}} \quad (5)$$

Then, using the sample height (sH) and the dbh of the sample height tree (DBH_{sH}), the equation was rewritten as follows to find β_1:

$$\beta_1=(sH-1.3)/(1-e^{-0.155793DBH_{sH}})^{\frac{1}{0.7}} \quad (6)$$

And therefore, total height can be found from:

$$H=1.3+\left[(sH-1.3)/(1-e^{-0.155793DBH_{sH}})^{\frac{1}{0.7}}\right](1-e^{-0.155793DBH})^{\frac{1}{0.7}} \quad (7)$$

Evaluation of the developed models for estimating stem volumes

The above equations can be used to predict the log assortment options available from a particular tree stem. This can be accomplished by predicting stem diameters at heights corresponding to the assortment lengths, and assessing whether the diameters are above the minimum top diameter threshold. All calculations can be made in a simple spread-sheet. Importantly, this method would only utilise data collected in a standard thinning control assessment, as described by Matthews and Mackie (2006).

However, the errors associated with each sub-model will contribute to a total combined error. This total error is the result of the output of the DBH to total height model (which has an error) being used as an input variable to the taper model (which also has its own error). Because multiple predictions are used to estimate the assortment volumes, these errors will also be propagated for each volume estimate. The methods for calculating the total error for using the two models together in this manner will require an extensive body of additional work. This was not within the scope of the present study.

However, an evaluation of the performance of the equations' ability to predict volumes was made. This was done by comparing predicted and actual volume results using the data from site 5. The stem volumes were estimated in 1 m sections from the base to the tip. The results in Table 6 show that residual error and bias were low. The overall SEE was 0.0098 m^3 per tree. The overall mean bias was small, at 0.00003 m^3. Figure 6 displays the predicted versus the measured stem volume of the validation data.

Table 6: *Statistics for the predicted volumes of the validation data.*

Plot	Top height (m)	QMDBH (cm)	Mean stem vol.[a] (m^3)	SEE $stem^{-1}$ (m^3)	Mean bias $stem^{-1}$ (m^3)	Predicted total vol. $plot^{-1}$ (m^3)	Measured total vol. $plot^{-1}$ (m^3)
1	13.60	12.10	0.06	0.0112	-0.003	1.84	1.74
2	9.70	13.00	0.06	0.0064	0.003	1.58	1.65
3	13.70	15.60	0.11	0.0102	0.001	3.18	3.20
Overall				0.0098	0.00003	6.59	6.59

[a] Measured.

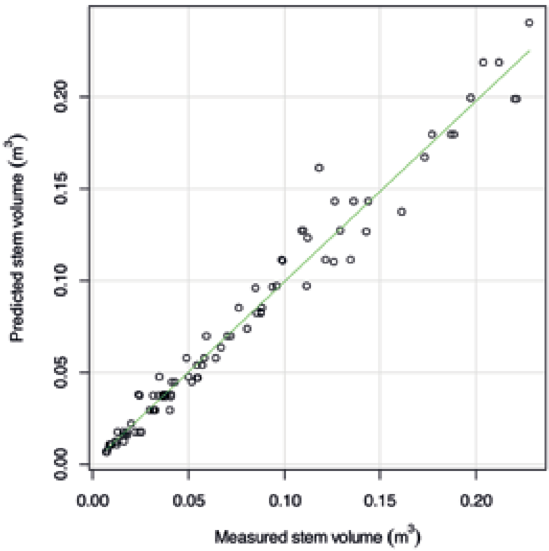

Figure 6: *Predicted versus measured stem volume (m³) of the validation data.*

Conclusions

For Sitka spruce first thinning plantations in Ireland, Kozak's taper equation has been parameterised to predict diameters along tree stems. To estimate the total height of trees, the Chapman Richards model was parameterised using the height and DBH for a single tree in each plot, and then applied to all trees in that plot. The taper function and DBH to height function could be implemented into a tool to predict the volume of different assortments in a stand prior to thinning. Importantly, it would not require any additional measurements beyond those normally taken in the thinning control measurement procedure. Overall, when compared to the validation data, the equations predicted the full stem length volume with a SEE of 0.0098 m^3 per tree, and a bias of 0.00003 m^3 per tree. These equations could be used for trees from 5 cm to 30 cm DBH, and for heights from 5.1 m to 16.0 m. With more data, the equations could be improved to predict outside these ranges.

In private forest holdings, the models developed in this study may help forest managers or owners plan the timing of first thinning, anticipate the harvesting resource capacity required, and may aid in the identification and marketing of specific product types to customers. Where a wood energy market is preferred, the equations could be used to estimate the additional volume recoverable by harvesting whole stems and cross-cutting in variable lengths.

However, further investigation is required on how the errors of the individual models will propagate to a total error. A trial of how the models perform in predicting the assortment volumes during a commercial first thinning should be undertaken. When fully validated, the models could be implemented into a simple spread-sheet program for distribution as a tool to practitioners. The practical implications of this work include:

- The ability for forest managers to predict the volumes of a variety of assortment options, where the dimensions of the assortments can be defined by the manager, and may assist in the marketing of timber from first thinnings prior to harvesting.
- The statistical models, comprising the basis of a practical tool, have been developed so that no additional measurements are required beyond the standard thinning control assessment procedure.
- The models will require field testing during commercial operations to fully evaluate their performance.

Acknowledgements

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The valuation of non-market forest benefits in Ireland: a review

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Abstract
Forests are associated with the production of tangible market goods, most notably timber. However, trees and forests are also valued as providers of recreation and for the conservation and enhancement of biodiversity, among other environmental goods and services. Such benefits are undoubtedly important to the welfare of individuals but, as public goods, they are not traded and, as a result, not assigned a monetary price with which their value might be identified. Within the context of sustainable forest management, which calls for the balancing of forest outputs, the absence of a metric with which to compare benefits increases the uncertainty and complexity of forest management and decision making. A range of valuation techniques has been developed in recent decades, which offer the possibility of identifying the value of non-market forest benefits in monetary terms. This review describes the principle techniques and gives an overview of their use in an Irish context.

Keywords: *Non-market benefits, forest valuation, forest policy.*

Introduction

Forests vary considerably in their composition and, correspondingly, the benefits they can provide to society are diverse. This relationship is further complicated by the process of forest management that can both enhance or diminish the range and quality of the benefits supplied by forests (Mattsson and Li 1999). Planting a forest on agricultural land has the potential to either enhance or diminish existing biodiversity levels and may increase the recreational value of a given area (Buscardo et al. 2008, Bateman et al. 2003). Such impacts are not traditionally included in the calculation of the value of the afforestation enterprise, but may have a significant effect on societal welfare. The economically opaque nature of such benefits and costs can result in poor management decisions on the ground and a failure to account for them sufficiently in wider national and international policies. These failures can threaten the long-term sustainability of commercial activity and ultimately societal welfare (Costanza et al. 1997).

In an analysis of multi-use forest management, Hall (1963) lamented the fact that forest managers and policy makers were expected to be omnipotent in their decision-making, given the range of forest outputs they were expected to account for. Specifically in an Irish context, Convery (1970) recognised the difficulty of accounting for "unquantifiable" benefits such as conservation and recreation in economic planning of afforestation. Under the relatively new paradigm of sustainable forest management

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(SFM), individuals involved in forest management and policy formation are required to account for the diverse, and at times conflicting, demands that society places on the goods and services that forests provide. One of the specific challenges to this goal is the lack of a comparable currency with which the necessary trade-offs between forest outputs can be made. In particular, this complicates identifying how much timber production should be sacrificed in order to maintain or enhance other forest benefits.

One approach to accounting for non-market benefits is to identify a monetary value for them, thus making them comparable to those already identified and valued by existing markets. Where such values have been identified, specific policies can be analysed using cost-benefit analysis that accounts for wider, societal effects (Hanley and Spash 1993). How the monetary values of such benefits should be identified and quantified has become of significant concern to researchers in recent years, particularly in the context of SFM (Adamowicz 2003). Identifying a monetary value for the benefits of trees and forests can assist in forest management, particularly of state forests, and the allocation of state funds to ensure the production of particular outputs (Garrod and Willis 1992). Non-market valuation methods are now an important element of US environmental policy and have been incorporated into federal law (Portney 1996, Hanemann 2006). Policy makers in the UK also recognise these methods. This includes the UK Forestry Commission, which has employed biodiversity values in some of their forest management plans (Garrod and Willis 1997).

From the perspective of Irish forest policy, non-market valuation methods may be particularly beneficial as the majority of forests in Ireland are plantations, established with a variety of goals in mind during the previous century. In addition, Ireland's ambitious afforestation plan involves a large investment by the Irish state in a resource that has the potential to provide significant economic, social and environmental benefits to Irish society. However, the planning and management of these forests will dictate the type and magnitude of these benefits. Irish forest policy has been influenced by the diversity of forest outputs since its inception, both directly and indirectly, and a limited number of non-market valuation studies have been conducted, but the extent of their influence is difficult to gauge.

What are non-market forest benefits?

In simple terms, non-market forest benefits refer to the diverse range of goods and services produced by forests that are not traded in a market and thus, usually, have not been priced. Although the term benefits is most commonly used, both positive and negative forest outputs should be recognised in policy formation. In addition, negative values may be held by some proportion of society for what is, in general, viewed as an environmental improvement (Clinch 1999). It is generally recognised that the demand for such benefits has increased in recent decades (Bishop 1998). Given their diverse range and complexity, the recognition and quantification of all goods and services associated with forests is essentially impossible (Adamowicz and Veeman 1998). Therefore researchers most frequently concentrate on those that are considered the most important in terms of scale and/or value, such as those associated with biodiversity, recreation, carbon sequestration, water and landscape (Clinch 1999, Bateman et al. 2003, Willis et al. 2003). However, forests can also produce other, sometimes more localised, outputs such as microclimate regulation, soil formation and stabilisation, the conservation (or destruction) of archaeology, the diversification of the rural economy and the absorption of pollution. Within these broad headings lie a variety of costs and benefits. For example, Pearce (1994) remarks that forests and forest management can impact on water directly by changing both its quantity and quality, in addition to being a potential controlling factor for pollution and sedimentation from other sources. The complexity of such benefits offers a significant valuation challenge as the available methodologies often treat complex multifaceted issues, most notably biodiversity, in a relatively simplistic manner (Nunes and van der Burgh 2001).

Many environmental goods possess the characteristics of being non-excludable and non-rivalrous, which have resulted in their exclusion from traditional markets that would normally dictate how a resource is exploited efficiently (Hanemann 2006). Rivalry, in economic terms, refers to the situation where the consumption of a good by one individual affects the ability of another to consume it. Many forest benefits are non-rivalrous; for example, individuals can derive value from the provision of habitat conservation or the sequestration of carbon by trees without affecting another's ability to experience the same benefit. Non-excludability refers to the situation where it is not possible to exclude an individual from consuming a good, for example it is impossible to prevent an individual from benefiting from carbon sequestration or from enjoying the external view created by a forest landscape. Weisbrod (1964) suggests that a clear distinction between private and public goods is not always possible and that a good may have elements of both depending on the perspective of the individual valuing it. It is important that these characteristics generally result in the absence of markets for many environmental benefits. In the absence of market derived price signals, environmental goods and services may be under- or oversupplied in relation to the demand of society.

The value of non-market benefits

Defining a concise concept of the nature of value has long troubled philosophers and economists. It is generally accepted, however, that something is considered valuable if a person is willing to trade something for it, either to gain or protect it, rather than solely measured by the price assigned by existing markets (Hanemann 2006). It is this idea that forms the basis of the methods adopted in valuing non-market benefits. In essence, studies that attempt to quantify the value of non-market benefits seek to identify the quantity of another good that an individual might trade to gain the benefit, while leaving them at the same level of welfare or utility (Pearce 2006). Although any tradable item could be employed for this measurement, using a monetary metric offers the advantage of being meaningful, recognisable and significant to most of society. Thus, most commonly, studies seek to identify the maximum amount of money that individuals might be willing to pay (WTP) to attain or protect the given benefit, either through directly surveying individuals or by attempting to reveal this value by analysing the behaviour of individuals in relation to the benefit. In this way the identified values are a reflection of the preferences of individuals for gaining or preserving an environmental good. It should be noted that an individual's willingness to accept compensation for the loss of a benefit should also be a legitimate measure of value but this is a more difficult measure due to issues of ownership and the potential to encourage protest behaviour amongst individuals that are asked to state their valuation of the benefit (Arrow et al. 1994).

Such a definition of value is controversial as individuals may wish to secure the future of environmental resources for ethical and other non-economic reasons (Sagoff 1989). Although such beliefs may be reflected in WTP values, it is generally accepted that valuation may not meaningfully account for them (Bateman et al. 2003). Furthermore, even authors who champion such methods warn against using them as the sole decision-making instrument, particularly in a situation of irreversible biodiversity loss (Hanemann 1994). Thus, although it may be possible to identify the economic value of forest benefits and the preferences that the public holds for them, such values must be interpreted correctly and within the limits by which they are defined.

Extensive research has been conducted on both the definition and categorisation of the elements that make up value and the various tools that have been created or adapted with the purpose of measuring the value of environmental goods. Total economic value (TEV) can be used to categorise a set of values associated with an environmental good (Batemen et al. 2003). The concept of TEV offers a taxonomic deconstruction of the range of values associated with a given environmental asset. These values can be broadly divided into use and non-use values; i.e. values that an individual derives from the good through its consumption or use, directly or indirectly; and values that individuals derive through non-utilisation of the good. Possessing such a framework can assist in identifying the correct valuation approach for quantifying a given benefit and also assist in avoiding double counting of benefits (Pearce et al. 2006). Figure 1 displays the primary components of TEV and offers some forest related examples of each type of value.

Use values are, in general, more readily definable and encompass the value assigned through the direct consumption or experience of a resource, for example the value derived from recreating in a forest park and the indirect use of a forest for carbon sequestration. In a forestry context, many direct use values are associated with an established market and/or monetary exchange such as that for timber. Recreation

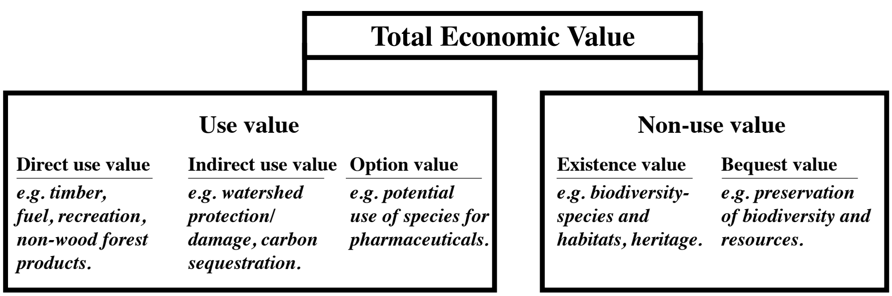

Figure 1: *The components of Total Economic Value with examples.*

can be associated with payments through entrance fees, but is often supplied freely to the consumer with the associated costs being covered by the forest owner and/ or the state. Indirect use values are generally associated with the broad range of ecological services supplied by forests such as water catchment protection or damage, air pollution reduction, and the sequestering of carbon for the regulation of the global climate. Although these services are rarely marketed, they are often interlinked with marketed activities. Identifying the use values associated with forests, such as those associated with timber production or recreation, is now generally seen as a problem of data collection and appropriate analysis (Adamowicz and Veeman 1998).

In addition to direct and indirect use values, Weisbrod (1964) argued for the inclusion of option values in resource allocation decisions, citing national parks, hospitals and public transportation as examples of services where the option of future use is valued even if never fulfilled, i.e. individuals value having the ability to use these services in the future. Similarly future information or technology may create a new output from the use of a resource that did not previously exist; this is exemplified in the recently formed carbon credit markets.

Forests are valued beyond the consumption related goods that they provide. Focusing on their use values solely has the potential to severely underestimate their true contribution to societal welfare and could result in the gratuitous exploitation and loss of valuable resources. Non-use or passive-use values are more difficult to identify and more controversial, but are now accepted as a legitimate source of welfare (Arrow et al. 1993). Numerous additional names have been assigned to this set of values or its constituents but they possess the common characteristics of describing changes in welfare that are not associated with the use of a resource. Krutilla (1967) recognised existence value as the value that individuals possess for the continuing existence of a good, i.e. that the loss of a good will impact on the welfare of individuals who have no intention or possibility to exploit it in any way. Non-use values can be composed of a range of factors, such as intergenerational altruism (bequest value) based on the belief that there is an onus on present societies to provide for and protect future generations, and ideas of stewardship linked to our sense of duty to the environment and the interests of non-human elements. Such values may have much to do with the uncertainty with which future resources will be available (Krutilla 1967). Both Weisbrod (1964) and Krutilla (1967) noted the difficulty of capturing such values in existing markets, although the example of charitable donations is given, but suggest they should be accounted for in resource allocation.

In many situations maintaining biodiversity levels will be valued for their positive role in the production of traded goods. The importance of habitats, in particular tropical habitats, for the potential production of pharmaceuticals has been recognised and quantified previously (e.g. Mendelsohn and Balick 1995). Biodiversity also has a role in environmental services, such as soil conservation and water regulation. However, it is clear from international environmental policies that species and habitats are acknowledged to enhance human welfare by their very existence (Nunes and van der Burgh 2001). These values are starting to be recognised in the market directly through trading schemes and, of particular relevance to forestry, sustainable certification (Adamowicz and Veeman 1998). In general, however, such values are excluded from existing markets and must be identified using non-market valuation techniques.

Non-market valuation methods

The failures of markets to account for the value of many essential resources has been recognised since the foundation of economics, but it was only in the last number of decades that researchers have developed methodologies to account for this shortcoming (Hanemann 2006). Both the nature of the benefits and the values that individuals hold for them depend on how the value of non-market benefits is identified. For example, a recreation visit to a forest has most frequently been valued, in the absence of an existing market, in relation to either the costs incurred by the individual in visiting the site or their stated willingness to pay for the visit in a hypothetical market. However, benefits associated with the existence of a species or habitat can be more complex and more controversial to value and rely on a more limited set of methods.

Methods for valuing non-market benefits are generally divided into three groups, the production function and other pricing methods, revealed preference methods and stated preference methods (Hanley and Spash 1993, Pearce 2006). The process of adapting previously derived values to new sites or services is increasingly employed as a cost-effective form of valuation, known as benefit transfer (Brouwer 2000). These methods differ fundamentally in how their result can be interpreted and the approach that they adopt in identifying monetary values.

Production function and pricing methods

Where forest benefits act as inputs to the production of a market good, the benefits can be valued in terms of their contribution to this production. Such an approach is often used to measure the services provided by ecosystems that impact on the welfare of society, as reflected in the production of goods that have an established market price. Such an approach is reliant on the effect of the environmental resource on the production-function of the market good being observable and quantifiable. Barbier (2000) describes the contribution of the area of mangrove forests to the production function of fisheries in Thailand and Mexico, i.e. how a change in the area of mangrove might influence the output of commercial fisheries. Where an existing market for the output does not exist, values can be derived using other valuation methods (Pearce 2006). For example, Clinch (1999) valued the effect of the Irish afforestation plan on water availability as the lowest cost associated with replacing the volume of water lost as a result of expanding forest cover, in this case as the cost of repairs to the water network. Researchers also use the cost of avoided damage as a measure of a benefit. An example might be the contribution of a wetland area or bog to the reduction of the scale of a flooding event and the cost of the damage to private property.

Bateman et al. (2003) argue that pricing methods do not capture value as such, since they do not identify public preferences or the demand for the given benefit, but rather identify a price for the benefit as reflected in a market good. Thus, the monetary value such methods derive may only be a partial reflection of the utility value of the benefit. Furthermore, such methods require that the relationship between an environmental and market good can be identified and quantified in a meaningful way, which may be impossible for many benefits (Pearce et al. 2006).

Revealed preference methods

Revealed preference methods describe the set of non-market valuation methods that identify the value of a non-market resource by examining related market based activity (Bishop 1998). As a result, such methods are principally limited to the analysis of use values, by their nature, and are most commonly employed to identify recreational benefits. In addition they cannot, in themselves, be employed to value future resources, although values may be transferred from comparable studies. Nevertheless, although constrained in their applicability, revealed preference methods are often preferred by researchers as they are based on actual behaviour and may, therefore, be less susceptible to the potential hypothetical bias in stated preference data. The two common forms of revealed preference methods are the travel cost method and hedonic pricing.

<u>Travel cost method</u>

The travel cost method (TCM) is based on an assumption of weak complementarity between an environmental resource, such as a forest park, and the cost accrued in travelling to or accessing the resource (Bateman et al. 2003). This is reflected in the observation that individuals living further from a site are expected to visit it less often due, in part, to the higher cost involved. Information is gathered by surveying visitors to identify where and how they travelled to the site and, potentially other visit-related costs. The concept of using travel costs to capture the recreational value of natural resources dates back to the 1940s (Hanemann 2006). The history of TCM is closely linked with forest recreation and it has been used extensively to value the recreational benefits of forest parks (Zandersen and Tol 2009). Traditionally, TCM studies are divided between those that survey individuals on site or that survey individuals from populations surrounding a particular site, known as individual and zonal TCM, respectively. Both approaches attempt to create a demand curve for the site of interest. However, the zonal method may give a more accurate depiction of visitation across the population as it also gathers data on non-users. An increasingly popular approach is to interpret and model visitation as a choice amongst alternatives, including the option of not visiting, which is known as a random utility approach. Although TCM methods focus on existing sites, by ascertaining how individuals would change their behaviour (increased/decreased visitation) in response to a change in the quality of a site, these travel costs can be used to value future changes (e.g. Hynes and Cahill 2007).

<u>Hedonic pricing</u>

Hedonic pricing (HP) decomposes a private good into a selection of attributes that are identified as impacting on its price. These attributes can include those relating to the surrounding environment (Pearce et al. 2006). House prices are most commonly employed in environmental studies. A large amount of data about the characteristics of houses, their location and the price they attained are gathered. Prices can then be modelled against these characteristics and the contribution of a public good, such as open space, forests or air quality, to the price of a house can be identified. The way in which these resources are included in the model differs and this affects the interpretation of the results. Both local forest cover and the distance between houses and forests have been included in models (Powe et al. 2007, Tyrvainen and Miettinen 2000). In general, forests are found to have a positive effect on house prices, but this may depend on forest composition. Garrod and Willis (1992) found that the area of broadleaf forests increased house prices whereas conifer forests had the opposite effect.

The HP method requires the collection of large amounts of data of sufficient quality and detail to avoid issues related to multi-collinearity, i.e. where two or more explanatory variables are correlated. In addition, the values attained from such studies can only be interpreted in the context of the private goods being modelled. The identified values are usually interpreted in relation to the effects of forests on landscape quality, but may also capture recreational benefits.

Stated preference methods

Some important forest benefits are not associated with existing behaviour or the production of other goods and so present a particular challenge to value through revealed preference or other methods. Valuation methods that survey individuals to ascertain directly their willingness to pay for a benefit, or willingness to accept compensation for its loss are described as stated preference valuation methods (Mitchell and Carson 1989). Such methods offer greater flexibility in the type of benefits and values they can quantify. In particular when examining non-use values associated with the existence or maintenance of biodiversity, stated preference methods may offer the only valuation alternative (Nunes and van der Burgh 2001). Ciriacy-Wantrup (1947) is credited as being one of the first to suggest using the willingness to pay of individuals as a measure of the value of a public good, in this case regarding soil conservation projects. Even at this early stage a number of potential weaknesses of the methodology were identified and survey design was highlighted as an important issue in combating strategic behaviour in reaction to suggested taxation changes.

Stated preference methods are generally composed of three sections (Portney 1994). Firstly, respondents are presented with a description of the good or policy in question; this should include the extent of the change of interest, how it will be managed and how respondents will fund it, as well as reminding them about the effect of this on their individual or household budget. Secondly, respondents are presented with the payment question, which can take a number of forms. Respondents may be asked to state the highest amount they would pay for the good, presented with the good and a monetary amount and asked whether they would pay or not; or presented with a range of different composite goods with differing costs and asked to choose their preferred one. In the final section, respondents are usually asked a number of socio-demographic and attitudinal questions to help to explain the choices of respondents.

Such methods are highly adaptable as they create hypothetical markets in which individuals can express their preferences, but for the same reason have been criticised as being arbitrary measures of attitudes (Diamond and Hausman 1994). The quantity and quality of information given to respondents, the method of elicitation, and the range and order of choices presented to respondents are some examples of contextual issues which have been found to influence expressions of preference and value (Gregory et al. 1993). However, these methods are recognised as producing meaningful estimates of values, including non-use values, when conducted following accepted guidelines (Arrow et al. 1993). Given their flexibility and the scope of values that they can investigate, stated preference valuation methods have been employed extensively to value forest benefits (Barrio and Loureiro 2009, Meyerhoff et al. 2009). Traditionally, stated preference methods have been divided into those that ascertain values for single benefits, contingent valuation methods and those that present a selection of alternative composite benefits and derive values for the components of those alternatives, choice experiments.

Contingent valuation

Contingent valuation (CV) studies present a single change in a good or service to a relevant sample of the population and derive a value for it directly through surveying (Mitchell and Carson 1989). A variety of techniques for attaining this value have been employed, including open-ended questions which ask respondents to state their maximum valuation; referendum style questions which present a value to respondents and ask them if they agree or not to the payment; and payment card type questions which present a selection of monetary values to respondents and ask them to choose one. Each of these methods have their strengths and weaknesses but the referendum style of questions have been recommended on the grounds that they may reduce bias and strategic behaviour on the part of respondents (Arrow et al. 1993).

Early CV studies focused on recreational values, such as the value of hunting (e.g. Davis 1963, Bishop and Heberlein 1979). However, CV studies became more ambitious in the types of goods and values that they investigated and were recognised in US federal law in the 1980s leading to greater examination of the methodology (Portney 1994). This resulted in a report commissioned by the National Oceanic and Atmospheric Administration in the US on the legitimacy of the methodology and the values that it claimed to measure (Arrow et al. 1993). Such studies have now become common in the literature examining forest benefits at the forest, local and national levels (Lindhjem 2007, Barrio and Loureiro 2009).

Discrete choice experiments

In a discrete choice experiment (DCE) respondents are presented with a selection of alternative goods or policies and asked to choose their most preferred (Hensher et al. 2005). These alternatives are composed of a number of attributes that are combined through experimental design methods so that the relative effect of each attribute on preferences for alternatives can be identified in the modelling process (Carson and Louviere 2011). Through the inclusion of a cost related attribute the trade-off that respondents might make between attaining an attribute change and foregoing an amount of money can be identified (Hanley et al. 1998). Adamowicz et al. (1994) are credited with conducting one of the first environmental choice experiments in their study of hunter preferences and this method has become increasingly popular in the literature examining non-use forest values (Meyerhoff et al. 2009).

DCEs have the significant advantage over CV in that they can produce a range of values for marginal changes in the composite attributes of the good (Hanley et al. 1998). In addition, DCEs may be more similar to respondents' day-to-day activities as they present a selection of alternative goods rather than an all-or-nothing choice, so they may reduce the risk of respondents rejecting the task in comparison to CV (Adamowicz et al. 1998). However, DCEs may place a greater cognitive burden on respondents than CV as they are required to make a series of relatively complex decisions. In addition, studies generally focus on the production of values for marginal changes to the attributes of goods or policies rather than their total value (Hanley et al. 1998).

Benefit transfer

Values derived from one site or for one benefit may be used to value a similar good through a process known as benefit transfer, where the value or the function derived to produce the value is transferred to a similar site (Brouwer 2000). Benefit transfer is reliant on the existence of suitable, comparable studies but may also be considered a methodology in itself. The primary advantage of this approach is the cost-effectiveness with which values can be produced (Brouwer 2000). A potential short-coming of the method is the generation of inaccurate values due to differences in the characteristics of the goods or the individuals valuing it (Ready et al. 2004).

Non-market benefits and Irish forest policy

Sustainable forest management (SFM) has been adopted as the central concept in Irish forest policy (DAFF 1996). This policy recognises the wide selection of forest outputs demanded by society, both market and non-market. Although SFM is considered a new development in Irish forest policy, non-market forest benefits did play a role in the past. State driven afforestation was often a political issue driven by concerns for domestic timber supply and rural development and employment (OCarroll 2004). Although such issues are related to economic activity, they are rarely accounted for in market derived prices and hence required state intervention to achieve them. As early as 1908, a Departmental Committee on Irish Forestry recommended that State forest development should take account of the "wider and less direct results of forestry, to its great influence upon the whole prosperity of rural districts and industries and to its social, economic, climatic and other national bearings" (Gray 1963).

A report prepared for the FAO in 1950 suggested Ireland should divide its policy in two parts, with one focusing on commercial forestry and the other on social forestry with an emphasis on rural development and employment in the west of Ireland (Cameron 1951). Although this suggestion was never officially adopted as policy, emphasis was placed on developing forestry in western counties in proceeding policies (OCarroll 2004). Gray (1963) suggested that the development of forest policy since the start of the 20th century may have been more concerned with wider forest benefits (self-sufficiency in timber supply, rural development and employment etc.) than considerations of financial return. Although such benefits were often mentioned, early forest policy failed to formally identify the range of benefits that the forest estate might produce (Convery 1970).

A number of financial analyses of forestry have been conducted in Ireland but although many identify non-market benefits, few actually account for them (a previous review can be found in Clinch 1999). The first monetary value assigned to such benefits in official policy appears to be in the government's strategic plan with a suggestion that "external benefits" from existing forests produce an annual output of €26.6 million (£21 million) (DAFF 1996). However, little explanation of this figure is offered other than relating it to potential timber value. The benefits mentioned include landscape, amenity, wildlife habitat, tourism and recreation. Similarly, Bacon (2003) assigned a value of €7.97 million to "leisure amenity and non-atmospheric environmental benefits" from the planting of 20,000 ha of forestry per year, calculated as 10% of the timber benefits. Bacon (2004) noted the lack of available Irish data on forest non-market benefits and included a recommendation that more research be conducted on forest valuation, in particular in relation to different management approaches.

Most Irish valuation studies have focused on the recreational benefits supplied by existing forests. Murphy and Gardiner (1983) conducted what appears to be one of the first attempts at valuing non-market forest benefits in Ireland. This study employed a form of CV to quantify the annual recreational value of Portumna Forest Park, described as being "under multiple-use management for timber production, recreation and wildlife habitat conservation", with a value of €7,199.77 (£5,670.28). The same authors describe a separate study that compared six different valuation methods, including forms of travel cost and stated preference methods (Murphy and Gardiner 1984). Although these studies were limited to relatively small sample sizes, single sites and recreation values, they mark a growing awareness of non-market values in forest management in Ireland and a change in the approach to identifying them.

The CAMAR study was one of the first attempts to quantify non-market forest benefits in Ireland on a national level (Ní Dhubháin et al. 1994). The study was ambitious in its scope and included both CV and TCM approaches at 13 forest sites across the Republic of Ireland to measure the value of a recreation visit. Using the CV data from that study, Scarpa et al. (2000) incorporated forest attributes into the modelling of WTP. Their study identified higher WTP values for forests with nature reserves and larger areas of broadleaves and deciduous conifers. This demonstrates that preferences and values held by the Irish population for forest-based recreational experiences are related to the composition and management approaches adopted in individual forests. Bacon (2004) derived the value of forest recreation by combining a value of €3.34 per person per visit, based on a UK model, and an estimation of 11 million forest visits annually. The annual visitation figure is derived by assuming an annual increase of 3% on the figures identified by Clinch (1999). The report also arrives at €79 million as a maximum recreational value if all forests, were transformed to the hypothetical ideal recreation forests composed primarily of broadleaves with some diverse conifers. Fitzpatrick (2005) conducted a household postal and an onsite survey of forest trail use and included a CV question in both examining willingness to pay per visit. The postal survey derived a WTP of €3.64 per visit, including non-users, from the sample of 441 who returned the questionnaire. An average value of €5.42 per forest visit was derived from the data collected on site at 12 forests. It is worth noting that mean WTP ranged from €3 to €8 depending on site. At the level of individual forests, Hynes et al. (2007) identified average travel cost as €7.36 and a consumer surplus of €12.33 for recreational visits to two urban fringe forests in Co. Galway using an individual travel cost method. The authors suggested that the location of the forest may explain the relatively large figure. Of particular relevance to the valuation of recreation are data on visitation rates. Table 1 summarises the available figures on national forest visitation rates per year from previous studies.

The government strategy to increase forest cover to 17% by 2030 (DAFF 1996) has also been the focus of a number of economic studies. Of perhaps most significance was the study by Clinch (1999), which included values for a range of non-market costs and benefits. A value was identified for the combined recreation, biodiversity and landscape benefits using a survey-based CV question. Individuals who were not supportive of the scheme were also given the opportunity to state whether they would be willing to pay to "avoid an increase in forestry". A reduction in water availability was valued as the equivalent replacement costs as a result of repairing water pipes and amounted to €2.54 million (£2 million) for the scheme. It was assumed that the eutrophication of water bodies would occur as a result of fertilisation, which was valued as a cost of €25.40 (£20) ha^{-1} based on a UK study. It was suggested that acidification would be avoided if appropriate planning and management procedures were followed and thus the cost was internalised. Carbon sequestration was valued at an assumed permit price of €19.05 (£15) t^{-1} C. Bacon (2004) derived biodiversity values from figures produced by Garrod and Willis (1997) for the conversion of remote conifer plantations in the UK, although reference was also made to the cost of biodiversity enhancement areas. The study also recognised landscape, water quality, health and heritage benefits and costs but did not quantify them.

Of particular importance to Irish forestry, given its high proportion of plantations, is the interaction of forest management and planning impacts and the values held by the public for the benefit provided for these forests. As part of the CAMAR study

Table 1: *Annual forest visit figures suggest a positive trend over time, although they are derived using different methods.*

Annual Forest Visits (millions)	Reference	Source
2.0	Ní Dhubháin et al. (1994)	Estimates from Forest Service and forest managers
8.5	Clinch (1999)	Household (7.7 m) and tourist (0.8 m) survey data
11.0	Bacon (2004)	Clinch (1999) data with assumed annual increase in demand of 3%
17.5	Fitzpatrick (2005)	Based on ESRI recreational trail walking data

(Ní Dhubháin et al. 1994), a household survey was conducted to investigate how the type of land on which forests would be established impacted on the values expressed by the public for forest expansion. They found that WTP was significantly higher for afforestation on marginal farmland rather than peatland, which was described as supporting higher levels of biodiversity. Clinch (1999) conducted an additional survey to identify the public's WTP for the afforestation programme to be conducted with broadleaves rather than conifers, which was valued on average at €13.26 (£10.44) for 10 years. Hynes and Cahill (2007) investigated how the inclusion of a wildlife viewing hide and a sculpture garden might increase the value of a small forest in Galway. Respondents were asked how their current visitation level would change as the result of the introduction of the hide and garden. They identified a value of €36.00 and €29.53 per person per year for the hide and garden, respectively. One of the few Irish studies to investigate the value of forest biodiversity examined recreationists WTP for different replanting strategies (mixed species, "natural" broadleaf, Scots pine (*Pinus sylvestris* L.) in comparison to Sitka spruce (*Picea sitchensis* (Bong.) Carr.) using CV (Mill et al. 2007). As part of the study respondents were asked to answer the question either from a personal or social perspective with the broadleaf and mixed options being most favoured by those taking a personal perspective.

It is important to note that many of the studies focus on a target forest cover of 17%, which was initially envisaged to be achieved by 2030. There has been a decline in planting rates in recent years that has been attributed to a number of factors, including competition from agricultural enterprises, land-use limitations imposed by agricultural and social schemes, uncertainty over future agricultural and forestry policy and cultural impediments to forestry adoption by farmers (Collier et al. 2002, McCarthy et al. 2003, Malone 2008). Lower planting rates obviously require a reinterpretation of derived values for benefits. At the same time, the composition of afforestation has changed significantly in recent years, with an increase in the use of species mixtures and broadleaf species. For example, 38% of the land planted in 2010 was composed of broadleaf species (Forest Service 2010). Such changes will affect public preferences and valuation of afforestation, which again would require a re-evaluation of the figures derived by previous studies. Increasing environmental restrictions will reduce potential costs associated with afforestation and the implementation of environmental enhancement measures are likely to be valued positively by the public. Thus the dynamic nature of forest policy poses a challenge to the interpretation of values that are often derived from one-dimensional studies.

In broader terms, moves to increase the production of non-market forest benefits (NMFB) may have unaccounted consequences. The imposition of stricter environmental controls has been suggested as a further disincentive to private land-owners establishing forests (Collier et al. 2002) and public access to private property is recognised as a contentious issue in Ireland. From the perspective of enhancing the production of NMFB, this is clearly a dilemma in that measures that increase them in an individual forest may reduce the total amount of land converted to forest. If afforestation remains solely an activity of private landowners, and if the supply of NMFB is to be increased, this dilemma is likely to persist.

Ensuring that landowners, foresters and local communities understand the diverse range of forest benefits may be one approach to maintaining and increasing their production. Primarily this is an issue of education and research. The potential contribution of forests to tourism may translate NMFB to a tangible direct income for local communities. Clinch (1999) found surprisingly high forest visitation rates amongst tourists and a general willingness to pay entrance fees. Additionally, private land owners could be paid directly for the public goods that originate in their property, thus incentivising their production or at least compensating for potential lost revenue from not maximising commercial activity. In an Irish context, it is worth noting that an additional barrier to farmers planting forestry is the perceived productionist mind-set of some, where land should be used for the production of food (McDonagh et al. 2010). The extent of this belief structure is difficult to gauge but the offer of financial compensation for limiting commercial activity may not in itself counteract this belief. In addition, the limitation of public access to private forests and land is unlikely to be motivated by a concern for financial loss alone. Nonetheless, the popularity of the rural and forest environmental protection schemes display the potential demand by farmers for such policies. From a forestry perspective, an examination of the success of the FEPS scheme in in encouraging afforestation and increasing NMFB would be worthwhile.

Conclusions and practical implications

Non-market benefits are increasingly recognised in national and international forest policy, but comparing them to those already traded in a market poses a significant challenge. A recognised approach is monetary valuation, particularly the use of stated and revealed preferences methods. Revealed preference methods have the advantage of being connected to actual behaviour, but lack the ability to value non-use benefits. Stated preference methods are more flexible but have been criticised as being potentially unreliable due to the hypothetical nature of the questions.

Irish valuation studies have been limited, but do include examples of both forms of valuation. Irish forest policy has changed significantly in recent years to take account of more diverse outputs, but relatively little information has been gathered as to how the general public value these changes. Further research into valuation methods is warranted given the general lack of existing Irish studies and the recognition of such values in forest standards. Studies that explore the connection between forest management and public valuation would be of particular benefit in assisting the incorporation of public preferences into management decision-making on the ground.

The main practical implications from the study are:

- Non-market forest benefits are being increasingly recognised in forest policy and management. The quantification of these benefits in monetary terms is likely to become more common as a method of comparing them to market benefits such as timber.
- The recognition of NMFB has resulted in the inclusion of environmental enhancement procedures in forest planning and management and in restrictions on practices and on afforestation in specific areas.
- It is important to note, however, that such benefits are important contributors to State and public support for afforestation and have the potential to offer

opportunities to forest owners to diversify forest outputs. However, questions exist as to how and to what extent NMFB should be encouraged in schemes that promote forest establishment for timber production by private landowners.
- The valuation of NMFB offers the capacity to quantify their value to society in a recognised way and may assist in the goal of sustainable forest management.

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Poor performance of broadleaf plantations and possible remedial silvicultural systems – a review

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Abstract
Over the last two decades planting of broadleaves has been part of forest policy. In addition to the provision of a range of ecosystem services, it is intended that this resource will have a direct economic stimulus through the supply of quality hardwood. A number of challenges must be met in order to achieve this objective, particularly as current observations would indicate that many first rotation broadleaf plantations comprise a relatively high proportion of poor quality stems. A literature review has been carried out on the probable causes of poor performance in broadleaf crops. Silvicultural systems to rehabilitate poor quality stands are discussed. Subsequent papers will deal with these silvicultural systems in more detail.

Keywords: *Broadleaves, silviculture, remedial action, plantation, stem quality, stresses.*

Introduction

This paper provides an introduction to the work of the COFORD/Teagasc/UCD B-SilvRD project with particular regard to the rehabilitation of poor quality broadleaf crops. This review discusses the possible causes of poor performance in broadleaf plantations. Prescriptions and silvicultural systems which may increase quality and performance are described.

Background

The national afforestation programme has resulted in significant increases in broadleaved planting over the past two decades:

- Since 1982 over 55,000 ha of broadleaf woodland have been established (Hendrick and Nevins 2003);
- In 1998 broadleaf planting accounted for 16% of all new planting; by 2010 it had more than doubled to 38% (Forest Service 2011).

This programme represents a considerable increase to the small national broadleaf woodland resource. In time this resource should provide a number of ecosystem services and contribute to the development of an indigenous hardwood timber resource. However, experience to date has shown that the establishment of quality broadleaves on first rotation green-field sites is challenging. Exposure, soil conditions, low intra-species competition due to low stocking densities and weed competition are all aspects of the open, green-field environment which present particular impediments

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to crop quality (Evans 1984, Savill 2003). The potential pitfalls of species selection, provenance selection and availability, ground preparation and a range of post-planting biotic and abiotic challenges are additional issues. Therefore, it is not surprising that first rotation broadleaf woodlands in Ireland contain a high proportion of trees with poor quality stems.

The causes of poor performance, with particular reference to Irish forest conditions, are reviewed in this paper. Silvicultural options that may improve the quality of these broadleaf plantations are also presented.

Species choice

Species choice is a fundamental element of successful plantation establishment and quality timber production. Information on broadleaved species site requirements is available for the UK and Ireland (Anderson 1961, Evans 1984, Hart 1991, Joyce et al. 1998, Pyatt et al. 2001, Horgan et al. 2003). Most broadleaves used for commercial timber production are more exacting in their site demands than the main commercial conifer species (Savill 2003).

The most recent data show that ash is the most widely planted broadleaf species in Ireland (Forest Service 2011). Ash grows best on soils with a pH 5.5 and above (Evans 1984). It forms a component of 13 of the 20 major native broadleaf woodland types in Ireland (Cross et al. 2010). Its inherent vigour and ability to colonise a wide range of sites may in some part contribute to its popularity. However, in the context of commercial timber production, ash is extremely exacting as to site conditions (Hart 1991, Horgan et al. 2003) such that there is very little room for error (Joyce et al. 1998). The best development of ash is on deep, moist, freely draining and fertile soils of about neutral pH. Such good sites are not widely available for planting and attempting to grow high quality ash on other site types is unlikely to be successful (Evans 1984).

In contrast to ash and other broadleaved species such as beech, sycamore and wild cherry, oak is relatively indifferent to site conditions. Joyce et al. (1998) record good, or at least moderate, growth of oak on most of the major soil types, ranging from upland podzols/brown podzolics to brown earths, grey-brown podzolics, and gleys. It may therefore be possible to produce economic oak crops over a wide range of site conditions (Savill 2003).

Few broadleaved species are suitable for growing as pure crops (Savill 2003). Species such as sycamore, cherry or Spanish chestnut perform better in mixtures or as a minor component of broadleaved woodland (Evans 1984, Hart 1991). Other species, such as birch and alder are becoming more widely considered for commercial planting (O'Dowd 2004, Fennessy 2004). These species may be better suited to some of the environmental challenges, outlined above, inherent in afforestation (Worrell 1999, Horgan et al. 2003).

Provenance

Provenance is potentially as important for broadleaved crop quality as species selection. For Britain, Hubert and Cundall (2006) comment: "Many broadleaved trees have been planted over recent decades with relatively little attention being paid to the provenance or origin of the seed used. Yet planting the incorrect provenance can result in the grower struggling with establishment over many years and, in some cases, total failure of the planting stock". Past examples of inappropriate provenance use can be found in relation to ash. The use of *Fraxinus angustifolia* Vahl. and its hybrids has not only resulted in poor quality, uneconomic plantations, but also threatens the integrity of the native ash gene pool (Cahalane et al. 2007). This situation has required considerable State investment in mechanisms to eradicate this species.

Based on UK trials, Hubert and Cundall (2006) make the following recommendations on seed sources, which have some application in Ireland:

- Seed stock from eastern continental Europe is usually poorly adapted to Britain in terms of growth rate and reduced survival. It may also be poorly adapted in terms of phenology and resistance to foliar disease. It should not be planted in Britain.
- Southward movement of genetic material within Britain (of the order of hundreds of kilometres) is likely to lead to a loss of vigour compared with local material.
- Northward movement of genetic material within Britain (of the order of hundreds of kilometres) may result in a gain in vigour compared to local sources, but the long-term implications are not known. Such material may prove to be more susceptible to late spring frosts or early autumn frosts which may not be fatal but may lead to poor stem form due to forking. Low temperatures in exceptionally cold winters that may be experienced once or twice in a rotation may be more seriously damaging.

Figure 1: *Birch seedlings of Norwegian and French provenance raised in the same UK nursery. The buds of seedlings on the right (French) have flushed, while those on left (Norwegian) have not, demonstrating the impact of provenance on an attribute that may affect survival after planting (Hubert and Cundall 2006).*

Adaption to local environmental conditions is fundamental to good vigour and growth habit. “In practice the most important improvement occurs because the new crop is well-adapted to the site, adaptation being a highly heritable character” (Zobel and Talbert 1984, p. 270). “Characters affecting timber quality such as straightness of stem or good natural pruning of branches are moderately heritable, so they can be improved…” (Matthews 1989). This suggests that a geographically appropriate and well-adapted native provenance (if available) may be a better choice than one which displays favourable phenotypic characteristics in its native habitat, such as stem form, but which originates from a geographically inappropriate area, particularly where the species displays a high degree of phenotypic plasticity.

The movement of Finnish birch provides a good example, whereby material that grows well in Finland has performed poorly in the UK/Ireland due to the species’ response to local environmental conditions (high phenotypic plasticity). With reference to the recommendations made by Hubert and Cundall (2006) for Britain, birch from Finland, or any area with a continental climate, may not be suitable for planting in Ireland.

Native provenances have evolved and adapted over long time periods and may be considered best suited to local conditions (Boshier and Stewart 2005, Little et al. 2009). However, as Felton et al. (2006) have shown, provenances from neighbouring localities can differ substantially in their performance. Native provenances are preferred for the establishment of commercial broadleaf crops, as reflected in afforestation guidelines with “native Irish” or “registered Irish” material being the first preference in most cases (Forest Service 2003) and Fennessy et al. (2007) highlight the importance of producing quality broadleaf planting stock from home collected seed. However, intermittent mast years and variable levels of seed production impact on native planting stock availability. The expansion of broadleaved planting in Ireland, as outlined previously, has resulted in levels of demand that exceed the capacity to produce native stock and the use of continental European material is widespread in broadleaved afforestation.

With reference to the early expansion of broadleaf planting in the 1990s, Joyce et al. (1998) point out that: “In recent years the rapid increase in the afforestation programme has resulted in demand for native oak seed far exceeding supply”. With increases in broadleaf planting generally, including the additional demands on native provenance material from the Native Woodland Scheme, the supply of native oak has continued to be difficult (Felton et al. 2006). Mechanisms to increase the availability of good quality native Irish material may greatly support broadleaf plantation quality. Felton et al. suggest ways to achieve this, although continuing difficulties in seed stand selection are highlighted also. Fortunately however, much work has been done in relation to the establishment of native seed orchards (Thompson et al. 2009). Taking cognisance of the unintentional use of *Fraxinus angustifolia* in the earlier years of the afforestation programme, the nursery sector can now supply all ash planting stock requirements from native sources (P. Doody, pers. comm.).

Establishment practice

Site preparation

Site preparation for broadleaves should provide a well-aerated, weed free planting position, improve drainage and break up compacted layers (sometimes associated with former agricultural land), in order to facilitate root growth and penetration (Hibberd 1991, Rodwell and Patterson 1994). Rodwell and Patterson did not favour extensive mechanical cultivation in relation to native broadleaf woodland establishment, primarily for ecological reasons. Furthermore, the quality of tree establishment may also be reduced by inappropriate mounding; "care should be taken to avoid bringing up too much subsoil as this does not provide as good a growth medium as topsoil" (Bulfin 1992). Indeed, planting into heavy and/or nutrient poor subsoils may well impede early growth and delay canopy closure.

Ground preparation should provide favourable soil conditions at the planting microsite, while having minimal impact on microtopography and site access. If this is not the case then such operations may promote loss of quality and hinder necessary future management operations.

Plant handling

One of the principal causes of poor survival and slow growth of newly planted trees is damaged plants through poor plant handling (Evans 1984). Root growth potential (RGP) and long-term plant vigour may be reduced through: desiccation; root bruising and tearing; respiratory loss; overheating; nutrient loss; and/or disease outbreak; resulting from even a very brief period of poor handling (O'Reilly et al. 2002, Colombo 2006). Birch is a good example: it establishes readily from planted bare root stock but is "extraordinarily susceptible" to root damage (Worrell 1999). Whereas poor handling of susceptible species such as birch may result in widespread failures, poor handling of more robust broadleaves such as oak may still lead to loss of form, e.g. through shoot dieback (Cabral and O'Reilly 2008).

General guidelines for correct plant handling and storage are readily available (Forestry Commission 2002, Teagasc, undated). The optimum period for lifting and planting should also be observed. For example, sycamore responds better to early season planting when the seedlings RGP is high (O'Reilly et al. 2002). Fundamentally the period of time between lifting and planting should be kept to a minimum.

Planting practice also impacts on crop performance. Tobin (2003) describes the common deformities in ash root systems due to poor planting practice. While young trees do have the ability to recover, plantation vigour, health and longevity are likely to be affected.

Careful handling and storage throughout the establishment process – from nursery to planting site – is critical to good survival, vigour and stem form, and may require close supervision (Tabbush 1988).

Stocking and configuration

It is generally recommended that broadleaves should be planted at close spacing – less than 2 m apart in and between lines – where timber production is a primary objective

(Rodwell and Patterson 1994). COFORD (2002) recommended that seedlings should be planted at a sufficiently high density to restrict lateral branch (and hence knot) diameter development and to encourage height rather than lateral growth. Bulfin (1992) recommends that broadleaves be planted as close as economically possible to ensure good stem form. Although seedlings are planted at relatively high densities on sites established through the afforestation programme, stocking rates are generally lower than those achieved through successful natural regeneration, so the young plantation must grow through its first vital years effectively in a free growth state (Bulfin 2003). This early lack of competition may lead to loss of form.

The potential quality benefits of securing natural regeneration within a woodland environment are discussed later. Joyce et al. (1998) suggested that one means to increase competition is to reduce spacing within the planting lines while maintaining more open gaps between lines. This configuration has been commonplace within the afforestation programme.

One method to reduce the effects of limited stocking densities is through the use of mixtures and the integration of nurse species. The use of mixed species plantations in broadleaved silviculture will be the subject of further communication. However, it is useful to examine how inappropriate mixture configurations may negatively impact on quality.

One rehabilitation trial currently underway demonstrates the likely implications of using an inappropriate mixture configuration. In this case, three rows of oak were planted between single rows of ash. Very poor early growth in the oak – possibly attributable to poor species/provenance choice, and/or inappropriate site preparation – resulted in the oak being heavily suppressed by the ash (see Figure 2). The ash, having so much canopy space, were effectively open grown and also of very poor form. In effect, the configuration provided inappropriate competition.

Appropriate stocking and planting configurations should be used with the aim of providing sufficient intra- and inter-species competition; and critically, management interventions are needed to ensure crop trees are neither suppressed nor released too quickly.

Figure 2: *Heavily suppressed oak (background) dominated by open-grown, poorly-formed ash (foreground).*

Weed control

The statement that weeding helps plants to "survive and thrive" is particularly true of broadleaves (Evans 1984). Weed competition represents the single greatest cause of plant loss and poor growth (Bulfin 1992). Moreover, avoidable delays in reaching thicket stage through poor weed control present a longer timeframe in which open-growing conditions and low levels of competition may result in increased loss of form.

Moisture stress from weed competition reduces the growth of broadleaves (Davies 1985). Cherry, for example, can more than double its annual height and basal area increment when grown in weed free conditions. This is primarily due to favourable soil moisture conditions (Kerr and Evans 1993). However, the regular mowing of competing weeds (grass) may reduce growth to about one quarter of the growth rates achieved by trees established under weed-free conditions. This occurs mainly because mowing stimulates fresh regrowth of the grasses, thus increasing the rate of moisture loss from the soil. An entirely weed-free site or one with a substantial proportion of bare ground adjacent to individual planting positions, maintained for 2-3 years after planting (Joyce et al. 1998) is usually the best way to establish a broadleaved crop (Evans 1984).

Disease

The susceptibility of tree species to disease and pathogens can be increased due to natural stresses, e.g. drought (Desprez-Loustau et al. 2006). Certain diseases such as canker in ash and cherry (*Pseudomonas savastanoi* Gardan et al and *Pseudomonas syringae pv syringae* van Hall, respectively) are quite common in broadleaf plantations. However, their occurrence may be greatly exacerbated by poor establishment and management practice (Joyce et al. 1998). Poor species/site matching, inappropriate provenance selection, poor plant handling and incorrect pruning all represent factors which may cause physical or physiological stress. This stress can predispose trees to attack by pathogens (Schoeneweiss 1981, Wargo 1996). In a Danish study on the occurrence of ash canker, Skovsgaard et al (2010) suggest that the incidence of infection increases with reduced tree vigour related to site factors and possibly silvicultural practice.

Poorly devised monocultures may contribute to the outbreak of disease (Kelty 2006), e.g. where the species/provenance is not well adapted to the site (Larsen 1995). Widespread outbreaks of canker in cherry in Ireland may have been associated with inappropriate planting patterns and it is thought that the susceptibility of the species may be decreased within different mixture configurations (O'Reilly 2006). Pautasso et al (2005) suggest that there is a strong relationship between tree species diversity and susceptibility to fungal pathogens, and propose that mixed species forests have a better ability to buffer disturbances. Larsen (1995) outlines how we can greatly increase our forests resilience to disease through the use of well adapted species and provenances, stand structures and silvicultural systems. The importance of such "effective" silviculture is magnified by the potential additional stresses applied to plantations as a result of climate change (Ray et al. 2008, Green and Ray 2009).

Climatic factors

Exposure

Exposure is one of the principal drawbacks of growing broadleaves in an open field situation. The term combines a number of effects such as elevation, windiness and aspect (Horgan et al. 2003). Stem form of trees planted on open fields may deteriorate due to late spring frost, exposure to cold and desiccating wind (Bulfin and Radford 2000).

Exposure and elevation are closely interlinked. As elevation increases, growing conditions tend to deteriorate. Many broadleaves prefer lowland conditions and are intolerant of higher elevations (Bulfin 1992). Attempting to establish productive broadleaved high forest above 300 m will rarely be worthwhile (Evans 1984). Persistent wind on exposed sites leads to crown deformation and poor growth (Willoughby et al. 2009), a situation that may be reduced by growing broadleaves with a conifer nurse or by retaining any existing cover (Evans 1984).

Frost

Unseasonal frost is particularly damaging for young broadleaves. Late spring frost may have the worst impact, often resulting in loss of apical dominance, forking and misshapen stems (Evans 1984, Kerr and Evans 1993). Over 60% of all incidences of damage recorded by the Forest Service under the Reconstitution scheme in the mid 1990s were attributed to frost (Anon. 1998).

Frost occurrence is linked to topography. Early and late frosts occur mainly on clear still nights when air in contact with surfaces flows down slopes to collect in valleys and hollows (Hart 1991). Frost-tender species, such as ash and beech (see Table 1), should not be planted in such locations. Species choice, therefore, plays an important role in reducing potential frost damage. However, good weed control may also significantly reduce frost damage of tender species because exposed mineral soil is more efficient in the absorption of heat, which is re-radiated at night (Joyce et al. 1998).

Browsing

A number of mammal species trample, browse, fray and strip the bark of broadleaves. They include: deer (*Dama dama* L., *Cervus elaphus* L., *Cervus nippon* Temminck, *Capreolus capreolus* L.); feral goats (*Capra aegagrus hircus* L.); domestic livestock; grey squirrel (*Sciurus carolinensis* Gmelin.); hare (*Lepus timidus* L.) and rabbit (*Oryctolagus cuniculus* L.) The protection of broadleaved trees from damage by mammals is vital if high quality timber is to be grown (Kerr and Evans 1993).

Deer

A recent report commissioned by Woodlands of Ireland on *Deer and Forestry in Ireland* (Purser et al. 2009) highlighted the significant threat to broadleaf plantations from a largely uncontrolled wild deer population. Deer populations in Ireland are increasing at unsustainable rates due to a number of factors. The economic and biodiversity values of forest habitats are significantly impacted by deer and these may

Table 1: *Susceptibility to frost damage of selected broadleaved species (adapted from Evans 1984).*

Frost sensitivity	Species	
Very susceptible	Walnut	*Juglans regia* L.
	Ash	*Fraxinus excelsior* L.
	Spanish chestnut	*Castanea sativa* Mill.
	Oak	*Quercus* spp.
	Beech	*Fagus sylvatica* L.
Moderately susceptible	Sycamore	*Acer pseudoplatanus* L.
	Horse chestnut	*Aesculus hippocastanum* L.
	Some poplars	*Populus* spp.
	Red and Italian alder	*Alnus rubra* Bong. and *Alnus cordata* Desf.
Hardy	Birch	*Betula* spp.
	Hazel	*Corylus avellana* L.
	Hornbeam	*Carpinus betulus* L.
	Lime	*Tilia x europaea* L.
	Elm	*Ulmus procera* Salis.
	Most poplars	*Populus* spp.
	Common and grey alder	*Alnus glutinosa* (L.) Gaertn. and *Alnus incana* (L.) Moench.

reach catastrophic levels over the coming decade if not managed. There is no national deer management policy in Ireland and no co-ordinated system of deer population distribution or density measurement. There is no single authority with jurisdiction over the necessary components of a comprehensive deer management policy. Purser et al. (2009) concluded that the consequences of not addressing deer management would result in deteriorating conservation status of native woodland as well as a reduction in hardwood and conifer wood quality, and an inability of broadleaf woodland to regenerate, thereby compromising their future viability.

Browsing and fraying from deer have severe impacts on stem quality (see Figure 3). Protection, using fencing or tree shelters, and/or localised culling is likely to be ineffective in the medium to long term. High deer numbers are very difficult for any individual forester or grower to address in isolation. Long-term effective control requires the sort of coordinated national approach as outlined in the Woodlands of Ireland report (Purser et al. 2009).

Squirrel damage

According to Joyce et al. (1998) the grey squirrel constitutes the most serious threat to the growing of broadleaves in Ireland. Grey squirrels can cause severe damage to broadleaf crops through bark stripping. This is compounded by the species' tendency

Figure 3: *Severe fraying and browsing damage by fallow deer in a young ash plantation.*

to attack older trees – from 10 to 40 years old – which has greater financial impact on the crop (Lawton 2003). Thin-barked species, such as beech and sycamore are most susceptible to attack, to the extent that they are not recommended for planting in those parts of Ireland with high grey squirrel populations. Unfortunately certain operations which aim to promote tree vigour – such as thinning – may exacerbate attack through increased sap flow (Rooney and Hayden 2002).

Carey and Hamilton (2008) report that the grey squirrel has spread dramatically over the past 10 years and is now present in 26 out of 32 counties in Ireland. Sightings west of the river Shannon have been few but there is a real possibility that the grey squirrel will eventually penetrate into woodlands west of the river. Substantial public funds have been invested in broadleaf planting over the last two decades; much of this is now at risk because of its susceptibility to bark stripping by the grey squirrel. While beech and sycamore appeared to be the species mostly at risk, Carey and Hamilton (2008) also reported a number of oak woodlands have been attacked in recent years by grey squirrel, with up to 85% of trees being destroyed. Experience in Britain has shown that other broadleaves are also at risk, particularly when grey squirrel numbers are allowed to go unchecked.

Much like the problem associated with deer, grey squirrel damage may be very difficult to control on a site by site basis. Trapping or other preventative measures are to be encouraged; however, a collaborative approach is required to address the situation on an island-wide basis. There is some evidence to suggest that locally increasing pine marten (*Martes martes* L.) populations may be responsible for a decline in grey squirrel numbers in some areas (Carey and Hamilton 2008).

Management practices

Pruning

Pruning is considered essential if the aim is to produce good quality broadleaved stems (Bulfin 1992). Individuals of any species may require formative pruning or shaping, with oak and beech the most likely due to a lack of apical dominance (Kerr 1992). Formative pruning is carried out on young trees to improve stem form up to a height of 3 m (Bulfin 2003). It involves the removal of multiple leaders and unwanted large branches to promote the development of clear, straight stems. When carried out correctly, formative shaping can be the most effective pruning treatment (Savill 2003) although Kerr and Morgan (2006) dispute this, recommending instead that a more secure way to obtain quality improvement is to use traditional pruning after a period of canopy closure. Formative shaping simulates natural competition which causes trees to lose side branches at an early age (Bulfin 1992). The use of close spacing (> 2,500 stems ha^{-1}) and good genetic stock can significantly reduce the need for this (Savill 2003).

In Lombardy in northern Italy, a plantation of walnut and pear (*Pyrus communis* L.) had the final crop trees pruned three times per year (spring, summer and autumn) for the first 6-7 years (Short 2011). The result of such intensive treatment is that a 20-year-old, 35 cm DBH, walnut tree can be worth €1,500 – a pear tree of the same size is worth double that value. The timber quality and economic rewards for such "hands on" management are obvious.

Thinning

Thinning is carried out for a number of reasons (Savill and Evans 2004):

- To reduce stand density and hence to reduce competition, leaving the remaining trees more space for crown and root development. This promotes stem diameter growth and usable sizes are reached more quickly.
- To remove dead, dying, and diseased trees, or any others that may cause damage to the remaining healthy ones.
- To remove trees of poor form: crooked, forked, or coarse trees, so that future growth is concentrated only on the best trees.
- To provide the owner with some revenue though, if this is not possible, as in some early thinnings, in the expectation of greater returns later in the rotation.
- More occasional reasons include maintaining light beneath the canopy to encourage grass growth for grazing, for providing poles for building, or for amenity, recreational, or ecological reasons.

The removal of diseased stems is important as it will reduce the risk of further infection throughout the remaining stand and therefore delaying thinning increases this risk. It is also important that the first thinning is done in a timely manner to ensure that crop vigour is maintained. Some species, such as ash, respond poorly to thinning once their crowns have become constrained and small. Others, such as beech and sycamore, can remain responsive to thinning even after a long period (Kerr and Evans 1993).

Thinning can also involve the early selection of final crop trees in broadleaved stands. The best trees are marked when they are young and favoured in subsequent thinnings. Because some inevitably become damaged or do not grow as well as expected, it is necessary to mark, at the outset, two or three times the number that will actually form the final crop (Savill and Evans 2004). Those selected are often known as Potential Crop Trees (PCTs). Recommendations for the number of PCTs to be selected in ash stands are given in Table 2.

Short and Radford (2008) provide four criteria to be used in selecting PCTs, as follows:

1. be free from disease;
2. have relatively good stem form;
3. have relatively good vigour; and
4. be evenly distributed throughout the stand.

The assessment of a broadleaf stand and selection of PCTs using the four above criteria could indicate whether the stand is performing poorly. If the required number of PCTs cannot be selected, then an alternative silvicultural regime may be necessary. Evans (1984) and Kerr and Evans (1993) both provide decision trees to assist in choosing the best silvicultural options for managing neglected broadleaf woodland (Figure 4). One of the main deciding factors is the number of relatively good quality, evenly-spaced PCTs present. If the density is less than 300 stems ha^{-1}, then the silviculture recommended is substantially different from that which would normally be carried out. The following section outlines the silvicultural practices involved in producing good quality broadleaved stands.

Table 2: *Number of potential crop trees (PCTs) to be selected in ash as per various authors.*

Author	Selected PCTs (stems ha^{-1})
Short and Radford (2008)	350
Horgan et al. (2003; p. 107)	350 – 400
Mutch (1998; p. 146)	≈ 330 (≈ 5.5 m spacing)
Garfitt (1995; p. 119)	200 (2 stems per 10 m square) [a]
Blyth et al. (1987; p. 28)	300 – 400 [b]
Evans (1984; p. 53)	≈ 350
Anon. (1955; p. 13)	247 (100 stems ac.$^{-1}$) [c]
Forbes (1904; p. 136)	371 (150 stems ac.$^{-1}$)

[a] Species not provided. Inference is that the number given is for broadleaves in general managed by the "Belgian thinning" system; a form of crown thinning.
[b] Species not provided. Number is given for broadleaves in general.
[c] Number given for heavy crown thinning. No species identified.

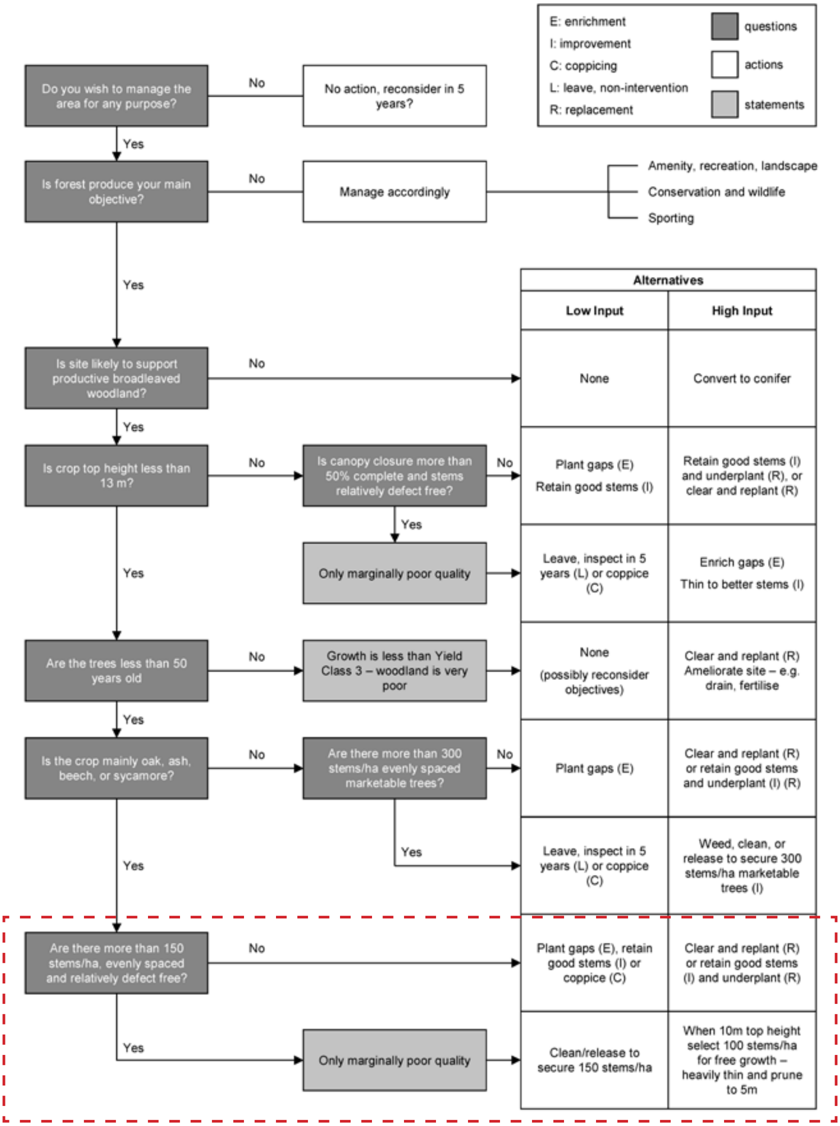

Figure 4: *Silvicultural options for managing neglected broadleaved woodland. Redrawn from Evans (1984) and Kerr and Evans (1993).*

Prescriptions and silvicultural systems to assist rehabilitation

The objective of the prescriptions and silvicultural systems outlined below is to improve the productive capacity of poorly performing broadleaved stands. Figure 4 provides some options; however, only those suggested in the highlighted decision box (red broken line) are considered here. Underplanting is one of the recommendations provided.

The microclimate of woodland is generally more conducive to tree establishment than an open-field situation. Therefore each of the systems outlined that include tree establishment maintain, to a greater or lesser extent, a proportion of canopy cover which will provide protection to the newly establishing trees and help protect them from the stresses of frost, heat, moisture stress and weed competition (Köstler 1956). This could be considered a form of a shelterwood system. The coppice-with-standards, the free-growth and the under-planting systems will be comprehensively reviewed in follow-on papers, but some of the key aspects of these systems are summarised below.

Shelterwood

High-forest systems in which an even-aged stand is established, normally by natural regeneration under a thinned overstorey, are known as shelterwood systems (Savill 2004). Shelterwood systems have advantages over clearfelling, including:

- Protection of frost-sensitive species, and protection against drought and cold winds;
- Protection of the soil from desiccation and weed colonisation;
- Less risk of soil erosion and run-off;
- Less risk of snow and storm damage with certain types of shelterwood;
- The best trees in the remaining stand can enhance their increment once the regeneration felling is carried out;
- Shelterwood systems can be regarded as aesthetically more preferable to clearfelling (Troup 1928, Matthews 1989).

Smith et al. (1997) state that a shelterwood system is superior to all others, except a selection system, with respect to protection of the site and aesthetic considerations.

Generally shelterwood systems utilise natural regeneration from seeding as the source of the new crop with, where required, supplementary planting carried out where insufficient natural regeneration has occurred (Matthews 1989). The pole-stage stands that we are considering in the context of this paper will likely be too young to produce sufficient seed to rely on a high enough level of natural regeneration to replace the stand (see Table 3). For example the best crops of ash seed come from trees between 40 and 60 years of age (Savill 1991). Therefore, underplanting in a shelterwood system is considered because it is an alternative that will maintain a relatively suitable microclimate for young trees.

There are two main shelterwood systems: uniform and group.

Uniform shelterwood system

Stands treated using the uniform shelterwood system are opened up uniformly throughout for regeneration purposes. Where natural regeneration is used, the usual

Table 3: *Seed production of broadleaved trees in Britain (Evans 1988).*

Species		Minimum seed-bearing age (years)
Alder (common)	*Alnus glutinosa* (L.) Gaertn.	15-25
Ash	*Fraxinus excelsior* L.	20-30
Beech	*Fagus sylvatica* L.	50-60
Birch	*Betula* spp.	15
Cherry	*Prunus avium* L.	10
Hornbeam	*Carpinus betulus* L.	10-30
Lime (small-leaved)	*Tilia cordata* L.	20-30
Norway maple	*Acer platanoide*s L.	25-30
Oak (pedunculate)	*Quercus robur* L.	40-50
Oak (sessile)	*Quercus petraea* L.	40-50
Spanish chestnut	*Castanea sativa* Mill.	30-40
Sycamore	*Acer pseudoplatanus* L.	25-30

method is to carry out a seeding-felling followed by secondary fellings. The seeding-felling opens the canopy in order to provide sufficient light for the short-term survival of seedlings from seed shed by the overhead trees (Troup 1928). The remaining trees are removed in one or more fellings at suitable intervals, thereby providing sufficient light for the continued survival of the seedlings (Troup 1928). The last of these secondary fellings is the final felling, which is carried out when the young crop is well established (Troup 1928). The shelterwood system requires long-term planning because, to increase the availability of seed, the stand is managed throughout its life to increase production of good quality seed. Frequent thinnings are carried out during the rotation to ensure that the future seed trees have large crowns and therefore are capable of producing a good crop of seed. The resultant trees should have long, straight stems free from branches which permit light to reach the ground and well-developed root systems so that they should be reasonably wind-firm when the stand is opened out during the seeding and secondary fellings (Troup 1928, Matthews 1989). The uniform shelterwood system was recommended by Everard (1985) as a good compromise between clearfelling and more intensive systems for UK broadleaf forestry. He also suggested that, where natural regeneration is not possible or appropriate; planting should quickly follow after the initial opening of the canopy.

Group shelterwood system

The group shelterwood system has many of the same principles as the uniform shelterwood system but differs in one major aspect: the stand is opened up in an irregular manner around groups of existing advance natural regeneration (Troup 1928, Matthews 1989). As the canopy around these groups is opened up, more favourable conditions exist for continued natural regeneration surrounding the groups. Areas where the canopy is opened up over the coming years gradually get larger until they eventually coalesce and consist solely of the new stand arising from natural regeneration. Similar to the uniform system, dense natural regeneration is required. This is unlikely to be the case for the pole-stage broadleaf stands considered here. However, both the shelterwood systems could be modified such that underplanting could be the means by which the stand is regenerated.

Underplanting

As has been alluded to above, the establishment of broadleaves on green-field sites is problematic because newly planted stock commonly experience multiple stresses, such as those resulting from exposure and aggressive grass / weed growth. When considering silvicultural systems that have potential to rehabilitate poorly performing broadleaf stands, it is prudent to take advantage of the benefits of an existing canopy. Therefore, underplanting seems to be a realistic means by which a young (10–20 years old) stand can be regenerated. Underplanting in an existing stand is common practice in continental Europe to introduce an understorey which will assist in the control of branching, including the development of epicormic branches, if a natural understorey is not already present (Kerr and Evans 1993). In Central Europe underplanting with beech has become common practice. In the 1950s and 1960s it was common practice in the UK to heavily thin oak stands and underplant with conifers to get an early return, whilst also encouraging the best of the oak to grow rapidly (Evans 1984). Underplanting is also carried out in shelterwood systems, where the natural regeneration is patchy and requires filling-in. Underplanting can also be used for the enrichment of an existing stand. Enrichment involves planting extra trees in a stand to increase the stocking of utilizable ones (Evans 1984). There are two main approaches to enrichment planting:

1. Opportunity planting – accept the bulk of existing crop and plant in gaps and poorly stocked areas where they occur;
2. Partial conversion – reject existing crop and systematically plant in swathes cut at intervals to produce strips of "better" forest interspersed with whatever develops from the poor quality woodland.

Coppice

Coppice is a forest crop raised from shoots produced from the cut stumps (called stools) of the previous crop (Evans 1984). Almost all broadleaf tree species coppice vigorously. European species that coppice freely are oak, ash, hornbeam, sycamore, lime, alder, hazel and Spanish chestnut (Troup 1928). There are a number of forms of coppice (see Table 4). However, only simple coppice and coppice-with-standards are described here.

Coppicing has been suggested by Evans (1984) and Kerr and Evans (1993) as a possible silvicultural system that may be employed to treat some poor quality woodlands. The current high demand and resultant price for fuelwood make coppicing appear increasingly attractive. The system may also allow the manager to select a number of stools and single their shoots with a view to allowing these to grow to

Table 4: *Coppice types and terminology (Evans 1984).*

Type	Description	Comment
Simple coppice	Crop consists entirely of coppice, all of which is worked on the same cycle (even aged).	May consist of only one species (pure) or several (mixed).
Coppice-with-standards	Two storey forest. Coppice (underwood) with scattering of trees (standards) being grown to timber size.	Standards may be of seedling origin (maidens) or develop from a stump shoot left for the purpose (stored coppice). Standards retained for a period of 3-8 coppice cycles.
Stored coppice	Tree or stand of coppice origin as a result of growing coppice on beyond its normal rotation.	Many woodlands, resembling high forest, are stored coppice owing to decline in coppice working this century.
Short rotation coppice	Arbitrarily designated as coppice worked on a rotation of less than 10 years to produce stick size material.	Provides material for many rural crafts. Recent interest in production of biomass for energy.
Pollards	Trees cut off at 2-3 m above ground so that the shoots which sprout are not in danger from browsing.	Regenerative mechanism identical to coppice. Formerly component of "wood-pastures" now little practiced in traditional form.
Underwood	General name for all coppice or scrub occurring under another tree crop.	

sawlog size, either by storing the coppice as an even-aged crop or by producing a coppice-with-standards system (see below). Coppicing a poorly performing crop may also facilitate supplementary stocking of gaps via natural regeneration or planting.

Coppice-with-standards

Coppice-with-standards is a silvicultural system that produces a multi-storied stand consisting of a lower storey of an even-aged coppice underwood and an uneven-aged partial upper storey of standard trees grown at wide spacing which is treated as high forest (Matthews 1989, Nyland 2002, Harmer 2004). The lower storey is regularly cut to produce small material whilst the objective of the upper storey is to produce large timber. Coppice-with-standards was at one time the principal system applied to the growing of hardwoods in Great Britain (Forbes 1904, Guillebaud 1927, Begley 1955). With the advent of a strong demand for small dimension hardwood timber for fuelwood, the system may once again have potential. The B-SilvRD project has established a coppice-with-standards pilot trial, which should provide useful information to this end for Ireland.

Free-growth

Free-growth is a silvicultural technique which stimulates crown development of selected trees, in order to achieve maximum radial stem increment (Jobling and Pearce

1977). It focuses management on a relatively small number of stems and maximises potential volume production and therefore reduce the length of the rotation compared to conventional management. The free-growth system involves the selection of final crop trees at an early stage in the rotation and then maintaining space around the crowns of the selected trees. A pilot trial site of a modified free-growth system in ash has been established in Ireland, which will provide information on the potential of this system.

Conclusions
There are many factors that can affect the performance of a broadleaf stand, some of which are under the control of the forester, others less so. The results can have a serious impact on the productivity and quality of a broadleaf crop, and therefore the potential economic returns. The Irish forest industry has, quite understandably, been focussed predominantly on producing high yielding conifer crops. Much of our silviculture is highly systematic, especially when compared with some of the broadleaf silviculture commonly employed in continental Europe. Broadleaf silviculture needs to be more subtle than the clearfelling system currently employed in Ireland if economic returns are to be achieved from the developing resource, especially if some of this resource is unable to produce quality timber without novel interventions. It is hoped that this paper, together with further planned communications, will stimulate discussion on broadleaved silvicultural practice. The following are the main practical implications that emerge from this review:

- Appropriate species and provenance choice are the foundation of successful plantation establishment. Incorrect choices are very difficult to rectify at a later date. Foresters should consider species choice carefully and realistically. Foresters also require ready access to suitable provenances of a chosen species.
- Ground preparation should improve the planting medium without physically compromising future management access.
- Broadleaves are often more suited to mixtures than to pure crops. Despite the added challenges of managing mixed species crops, they may convey some advantages. Their increased use should be promoted.
- Deer and squirrel damage are major issues impacting on broadleaved establishment and quality. The forest industry should continue to build upon the work carried out in this area and encourage a national collaborative approach to address these problems.
- Throughout the rotation, broadleaved plantation quality relies on timely and appropriate management interventions. This relies on on-going development of silvicultural systems adapted to first-rotation broadleaf plantations in Ireland.

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Possible silvicultural systems for use in the rehabilitation of poorly performing pole-stage broadleaf stands – Coppice-with-standards

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Abstract
This paper is a review of the coppice-with-standards system, a system that may have potential for the rehabilitation of some poorly performing pole-stage broadleaf stands. The system was once a very common system throughout Europe, producing much needed fuelwood and sawlog. Its decline in Ireland, the UK and elsewhere was primarily due to market forces. This review was conducted because the system may have potential once again due to the recent increased demand for firewood. Coppice-with-standards can provide material of various sizes to supply local demand for fuelwood, pulpwood, fencing material and sawlog. The system also has non-market benefits such as amenity and biodiversity values. One disadvantage of the system is that it requires greater silvicultural skill to manage to a high standard. The coppice-with-standards system is being trialled as a means to rehabilitate a poorly performing 19-year-old stand of ash:oak mixture.

Keywords: *Broadleaf silviculture, management, coppice-with-standards, rehabilitation.*

Introduction

As part of a Teagasc 5-year COFORD-funded research programme on the silviculture of broadleaf plantations (the B-SilvRD project) with UCD, silvicultural systems for the rehabilitation of poorly performing pole-stage (10 to 20-year-old) stands are being investigated. One such system being considered is coppice-with-standards. The history of coppice-with-standards, its management, species suitability, products and yield from the system, and its advantages and disadvantages are reviewed in this paper.

Coppice-with-standards

Coppice-with-standards is a silvicultural system that produces a multi-storied stand consisting of a lower storey of an even-aged coppice underwood and an uneven-aged partial upper storey of standard trees grown at wide spacing which is treated as high forest (Matthews 1989, Nyland 2002, Harmer 2004). The lower storey is cut regularly to produce small material while the objective of the upper storey is to produce large timber. The system is also sometimes called "compound coppice" or "stored coppice". In French it is "taillis sous futaie" and "taillis compose"; in German "mittelwald" and Spanish "cortas en monte bajo con resolves" or "monte medio".

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History

Oak (*Quercus* spp.) coppices were probably not uncommon in Ireland before modern forestry (Rackham 2010). Hayes (1794) refers to oak being managed as coppice-with-standards in Ireland. It was at one time the principal system applied to the growing of hardwoods in Great Britain (Forbes 1904, Guillebaud 1927, Begley 1955). The system has a long history of use in Europe and has only fallen out of favour during the last century. A form of coppice-with-standards appears to have been practiced in Germany from about 600 A.D. (Troup 1928). The standards consisted of forage-yielding species such as beech (*Fagus sylvatica* L.), oak and fruit trees which provided some sustenance to the cattle and pigs that were allowed to graze in the stand. Forest grazing within coppice-with-standards was still in evidence in the 19th century in Germany (Groß and Konold 2010). There are records of the system being used since the 12th century in Melton Constable Park, Norfolk, U.K. (Troup 1928) and it was the principal broadleaf silvicultural system in Great Britain up to approximately the end of the 19th century. Evelyn (1670) refers extensively to coppice management in Britain. In Ireland industrial development, particularly glass making and iron smelting, later began to reduce forest cover significantly. Many industries, from salt-making to iron-smelting, from pottery to dyeing, resulted in a great demand for charcoal for use in their furnaces (Neeson, 1991). In England, coppicing was practised by ironmasters to ensure a continuous supply of the best charcoal, derived from twenty-five-year-old oak coppice. All the known ironmasters in Ireland were Englishmen and were likely familiar with coppicing. McCracken (1971) argues that, except in Wicklow, no such management was carried out in Ireland and that, if it had, the woods could have been preserved. However, Rackham (2010) posits that coppice-woods could have been present in a large scale at one time because Viking buildings in Dublin were made extensively of wattle. House walls, wooden pathways and property fences would all have been made of woven hurdle panels and would have required vast quantities of long, straight hazel (*Corylus avellana* L.), willow (*Salix* spp.) and ash (*Fraxinus excelsior* L.) rods or underwood (O'Sullivan 1994). The Civil Survey (1654-6) records "underwood" and "copps" (Tomlinson 1997), indicating that some form of coppice management was being carried out. The earliest record of coppice management (i.e. rotational felling of underwood in fenced woods) from the Watson-Wentworth estate in Co. Wicklow was 1698 (Jones 1986). Young (1780) also mentions coppicing in the logs of his travels around Ireland in the 18th century, some with forty-year rotations. The coppice-with-standards system was also being employed on some Kilkenny estates early in the 19th century (Tighe 1802), though this appeared to have decreased in popularity, with some former coppices having been abandoned or neglected by this stage. A survey of Co. Wicklow woodlands in 1903 demonstrated that the system was still popular there, with almost 60% still being managed as coppice-with-standards (Nisbet 1904). Attentive landlords would fence copses to protect the regrowth from grazing animals. One of the first laws enacted on forest management was in the 16th century, which required enclosure for four years following coppicing (Bosbeer et al. 2008). Many scrub woods of the Watson-Wentworth estate were managed as coppice woods, but they were not fenced and it was this that distinguished them from the coppices (Jones 1986). A survey of the

Watson-Wentworth-Fitzwilliam estate coppices, carried out in 1724, often remarked on the presence of fencing (Carey 2009). A similar survey of 1728 described four coppices as having been destroyed by cattle (Carey 2009).

The demand for coppice produce rapidly declined in much of Europe from about 1870 until, by the early 20th century, it almost ceased to exist (Savill et al. 1997). The introduction of new inventions and technologies during the industrial revolution made available cheaper and better alternatives to the traditional forest produce. Efficient transport provided by railways also enabled coal to be taken to the countryside, largely replacing fuelwood. In Britain, the demand for large timbers for ship building declined and the use of coal and coke increased in industry, all adding to the demise of coppice-with-standards. While the data in Table 1 are not directly comparable, they do indicate a trend of decrease in the area managed using coppice-with-standards in Britain during the last century.

It was also fairly widely practiced until the middle of the 19th century in Switzerland (Troup 1928). In the early 20th century, almost all of the private and communal broadleaved forests in France, about 35% of the total forested area, were managed as coppice-with-standards (Troup 1928). Demorlaine (1907) provided statistics for the area of forest in France managed under coppice-with-standards. The total of over 5 million ha was slightly more than half of the total forested area, 4.9 million ha of which were privately or communally owned. Even in the 1980's, there was still a substantial area (3.9 million ha) managed in France using this system, of which over 2 million ha were privately or communally owned (Auclair 1982). The system is still widely used in France (Garfitt, 1995), where it is the most common silvicultural system (Du Bus de Warnaffe et al. 2006). It is also quite common in Belgium. Rondeux (1991) stated that the major stand types in private woodlands in the Wallonian region were conifer (55%), coppice-with-standards (20%), coppice (11%) and hardwood high forest (14%). In Austria, half of the ca. 150,000 ha of oak stands are managed as coppice or coppice-with standards (Hochbichler 1993). Over 3.5 million ha of Italian forest, 43% of the total forest area, are currently managed as coppice-with-standards, where the standards are left to produce seed for stump reproduction (Piussi 2006). It is surprising that a silvicultural system that is still in extensive use in parts of continental Europe was once relatively common in Ireland and the UK, but has so fallen out of favour during the last two centuries.

Management

The management of coppice-with-standards requires greater silvicultural skill than the majority of other silviculture systems. Generally, the forest is arranged into a number of coupes, also known as cants, corresponding to the rotation length of the coppice, such that one coppice coupe can be harvested annually. The coppice rotation length is dependent on the species, site productivity and product size required, but is normally from 10-30 years. The overstorey rotation is a multiple of the coppice rotation such that, if the coppice rotation is r years, the overstorey rotation could be $2r$, $3r$, $4r$, $5r$ years etc. As each annual coupe in turn becomes due for felling, the following operations are carried out in it (Troup 1928, Matthews 1989):

Table 1: *Estimated areas (000s ha) of simple coppice and coppice with standards recorded in surveys carried out in Britain during the 20th century (after Harmer and Howe 2003).*

Survey Year	England		Wales		Scotland		Britain			
	C	**S**	**C**	**S**	**C**	**S**	**C**	**S**	**Total**	**Comments**
1905[a]	215		6		9				230	Data from Board of Agriculture returns.
1913[a]	208		8		11				227	
1924[b]	31	163	7	8	2	2	40	173	213	Based on questionnaires, minimum area of each woodland = 0.8 ha.
1947	41	91	7	1	<1	<1	48	92	140	Very detailed field survey, minimum area of each woodland = 2 ha, needed minimum of 15 standards ha^{-1} to classify as **S**.
1965	18	10	<1	n/a	n/a	n/a	18	10	29	Field survey, minimum woodland area 0.4 ha, minimum of 15 standards ha-1 for **S**, maximum coppice stem diameter 19.4 cm at breast height (≡ 6" quarter girth). Areas of different types of coppice do not include Forestry Commission's 840 ha, but this is included in the total.
1980	26	11	2	<1	<1	<1	28	12	40	Field survey, minimum area of each woodland = 0.25 ha, minimum of 25 standards ha^{-1} for **S**, maximum coppice stem diameter 15 cm DBH.
1997[c]	11	10	<1	n/a	<1	<1	12	11	23	As 1980, except minimum woodland area = 2 ha.

C = Simple coppice.
S = Coppice with standards.
[a] In 1905 and 1913 coppice types were not separated.
[b] Figures estimated from county data. Prior to 1924 data for Monmouth was included in totals for England.
[c] Data from National inventory of Woodland and Trees carried out between 1995 and 2000.
n/a None recorded in this survey.

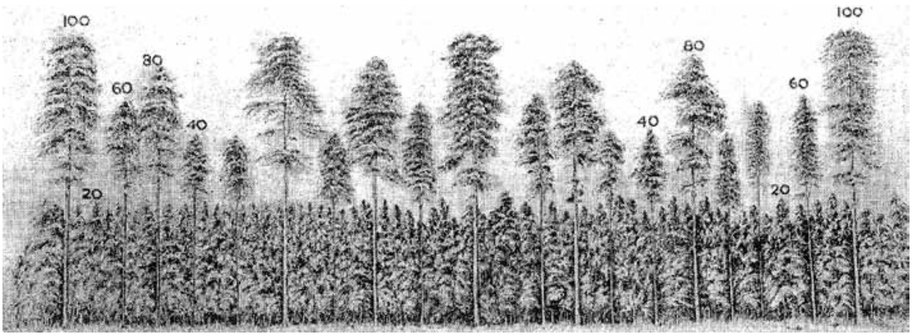

Figure 1: *Coppice-with-standards. Underwood rotation = 20 years; Overwood rotation = 100 years. Numbers denote age of standards (Schlich 1910).*

1. the coppice is clear cut;
2. some existing standards are reserved for at least one more coppice rotation, whilst the remainder are felled;
3. a number of new standards of similar age as the coppice are selected from natural regeneration, preferably from seed origin, and reserved. If there is insufficient natural regeneration, then transplants can be used. Standards that have derived from seed origin are called maidens;
4. vacancies caused by the removal of standards or the death of coppice stools are filled up using seedling natural regeneration or transplanted seedlings to ensure a future supply of both coppice and standards.

The result of the above operations, after numerous coppice rotations, is a multi-aged stand that consists of an even-aged coppice understorey with a multi-aged overstorey, as illustrated by Figure 1. The age of each class of standard is a multiple of the coppice rotation age. The terms used to denote these classes are given in Table 2.

Table 2: *English, French and German terms used to denote the several classes of standards in coppice-with-standards (Demorlaine 1907, Troup 1928, Matthews 1989).*

Age class	English	French	German
1r	Teller	Baliveau, Baliveau de l'âge	Lassbaum, Lassreis, Lassreitel
2r	2nd class standard	Moderne	Oberständer
3r	1st class standard	Ancien (de 2e classe)	Hauptbaum
4r	Veteran	Bisancien, Ancien (de 1ère classe)	Alter Baum, Altholz
5r	—	Vielle écorce (de 2e ou 1ère classe)	—

Note: r = one coppice rotation

The key to successful coppice-with-standards management is getting the right balance of standards per ha and the right distribution of ages (Law 2001). The number of standards to be reserved will depend on (Cheyney 1942):

1. the target rotation age of the standards;
2. the target diameter at felling of the standards;
3. the shade cast by the standards and the shade-tolerance of the coppice species.

The percentage of the total area allotted to standards should be decided upon before any cutting is carried out (Hawley 1921). According to Mutch (1998) the crowns of the standards should not occupy more than one-third of the area, although Hart (1991) suggested that they should occupy 30 – 50% of the ground area. Obviously, this should vary depending on the density of shade cast by the overstorey and the shade tolerance of the coppice species. The area occupied by the standards should be apportioned equally amongst each of the age classes (Brown and Nisbet 1894, Crowther and Evans 1986, Harmer and Howe 2003). This requires that the number of stems of each age class is reduced with increasing age and canopy size (see Table 3). Harmer and Howe (2003) take this one stage further to illustrate how these numbers can be derived, when the proportion of the area is divided equally between the different age-classes of standard (Table 4). This assumes that the standards comprise 40% of the canopy cover.

Table 3: *Proportion of standards reserved by age-class.*

Age class of standard	1*r*	2*r*	3*r*	4*r*	5*r*
Brown and Nisbet (1894)	16	8	4	2	1
Schlich (1910)	20	12	3	2	1
Adapted from Troup (1928)	50	30	20	10	
Matthews (1989)	50	30	20	10	
Crowther and Evans (1986)	50	30	13	7	
Demorlaine (1907)[a]	80	50	6		
Decocq et al (2004)	*80*	*40*	15	5	

[a] Assumes oak on 50-year coppice rotation, 150-year sawlog rotation.

Table 4: *Number of standards of different age classes in coppice cut on a rotation of 20 years using data adapted from Crowther and Evans (1986) by Harmer and Howe (2003).*

Age class	Number of stems to remain (ha^{-1})	Approximate canopy cover (m^2)	
		Average Tree	Total
Teller	50	20	1,000
2nd Class	30	33	1,000
1st Class	13	77	1,000
Veteran	7	143	1,000
Total	100	30	4,000

According to Matthews (1989), a higher than normal number of tellers is sometimes reserved to protect young coppice shoots from frost. Once the risk of damage has passed, the tellers are thinned to their required number. In 1749, the stocking of standards in existing coppices of the Watson-Wentworth/Fitzwilliam estates in Co. Wicklow ranged from 9 – 129 acre^{-1} (14 - 195 ha^{-1}) (Jones 1986). This illustrated that there was great variability in the stocking standards.

Species selection

The underwood must consist of species that can tolerate some shade, produce satisfactory stool shoots and also be marketable in small dimensions (Köstler 1956). There is very little information on species choice for coppice-with-standards in Ireland. Rackham (2010) makes mention of remnants of sessile oak (*Quercus petraea* (Mattuschka) Liebl.) coppice in Co. Wicklow. Sessile oak is listed again by Jones (1986) as a constituent of coppice in Wicklow. Other species also used were birch (*Betula* spp.), hazel, ash, willow, alder (*Alnus* spp.) and holly (*Ilex aquifolium* L.). In addition to pure oakwoods, valley floors and lower slopes would have birch-hazel-oakwoods; higher elevations and steep slopes: birch-oakwoods without hazel; steep slopes with freely draining soils: ash-hazel-oakwoods; wet ground: alder and willow. In England, the understorey of coppice-with-standards usually consisted of a mixture of species including alder, ash, beech, birch, cherry (*Avium* spp.), elm (*Ulmus* spp.), field maple (*Acer campestre* L.), hazel, hornbeam (*Carpinus betulus* L.), lime (*Tilia × europaea* L.), oak, sweet chestnut (*Castanea sativa* Mill.), sycamore (*Acer pseudoplatanus* L.), sallow (*Salix* spp.) and aspen (*Populus tremula* L.), the last two regenerated from suckers (Matthews 1989). These species may also be suitable for use in Ireland. The underwood can also occur as a monoculture, particularly of ash, hazel, oak or sweet chestnut (Matthews 1989). The most common understorey species in England is sweet chestnut. Oak is the most common overstorey species (see Table 5).

Table 5: *Area (ha) of coppice-with-standards in England by principal species of both coppice and standards (Forestry Commission Census of Woodlands and Trees, 1979-82 (Evans 1984)).*

Principal species of standard	Principal species of coppice						Total	% of total
	Sycamore	Ash	Sweet chestnut	Hornbeam	Hazel	Other species		
Conifers	0	0	16	4	0	0	20	<1
Oak	97	173	4,897	1,594	1,444	2,728	10,933	95
Ash	8	20	0	88	21	0	137	1
Sweet chestnut	0	0	353	0	0	0	353	3
Other broadleaves	10	0	9	11	0	0	30	<1
Total	115	193	5,275	1,697	1,465	2,728	11,473	100
% of total	1	2	45	15	13	24	100	

The overstorey is suited to light-demanding species with rapid growth and sufficiently good, valuable timber that can compensate for the loss of increment in the underwood (Troup 1928, Köstler 1956) and may be the same as, or different from, the understorey species (Crowther and Evans 1986). The standards should ideally have strong apical dominance, thick bark, a deep root system and cast only light shade (Crowther and Evans 1986). In the Watson-Wentworth estate, the standards were mostly oak (Jones 1986), a species that casts a light shade which doesn't inhibit the underwood to a great degree (Bagneris 1882). It has also been suggested that oak was possibly grown as a standard in coppice in the Tullynally estate in county Westmeath in the 19th century (Lefort et al. 1998). Other species that Bagneris (1882) recommended for the overstorey are ash, the common elm (*Ulmus procera* Salisb.), sycamore and Norway maple (*Acer platanoide*s L.). Troup (1928) recommended ash, poplar, cherry, robinia (*Robinia pseudoacacia* L.) and birch as the most suitable species as standards due to their light crowns. However, it is believed in Britain that some open-crowned trees, such as ash and birch, make unsatisfactory standards because coppice grows poorly beneath them, despite their thin crowns; this may be due to their dense rooting near to the soil surface (Matthews 1989). However, Harmer and Howe (2003) postulated that ash and birch may be more suitable as standards than species such as beech, lime and, to a lesser extent, oak because they have lighter crowns and cast less shade on the understorey. Economically, ash may be particularly suitable in Ireland due to the market for fast-grown ash for hurley sticks and its inherent suitability for fuel wood. Light-foliaged conifers, particularly larch (*Larix* spp.), can also make suitable standards (Troup 1928, Köstler 1956). Species identified in the literature as not being suitable are beech, lime and hornbeam due to their heavy crowns (Bagneris 1882, Troup 1928, Crowther and Evans 1986, Harmer and Howe 2003) and hazel because it only grows to a maximum height of 12 m (Crowther and Evans 1986).

Yield and products

The coppice-with-standards system produces timber of various sizes from small diameter to large, which is suitable for various markets. Lanier (1986) provides an indication of the assortments possible in France from various silvicultural systems (see Table 6 below). The greatest proportion of product is fuel wood. Other coppice products include thatching spars, turnery products, pulpwood, round, cleft or sawn fencing, fence posts and charcoal, dependent on species (Evans 1992).

Table 6: *Summary of different assortments derived from forests in France (% of total production) from Lanier 1986).*

Silvicultural regime or system	Waste and small wood	Fuel wood	Pulp and board wood	Sawlogs and veneer logs
Broad-leaved high forest	18	34	17	31
Coniferous high forest	13	14	25	48
Simple coppice	15	65	20	0
Coppice with standards	16	58	20	6

Table 7: *Estimated diameter at breast height of different age-classes of standards of various broadleaf species.*

Age class		Teller	2^{nd} Class	1^{st} Class	Veteran
Number of stems to remain (ha^{-1})		50.0	30.0	13.0	7.0
Approximate average tree canopy cover (m^2)		20.0	33.0	77.0	143.0
DBH of standard (cm)	Ash	21.1	28.1	44.9	62.6
	Birch	25.2	34.1	55.3	77.5
	Cherry	21.3	30.7	52.9	76.2
	Chestnut	21.1	34.6	66.6	100.3
	Oak	21.3	30.5	52.4	75.4
	Sycamore	23.3	31.0	49.3	68.5

Using the data from Table 4 and the regression equations of Hemery et al. (2005) relating individual tree canopy area to DBH, the DBH of the standards of various species can be estimated (Table 7). This illustrates the different sizes of material that can be produced by the coppice-with-standards system and their associated quantities. Using oak as an example, after the second coppice rotation, 20 standards with approximately 21 cm DBH can be harvested, together with 17 standards with approximately 31 cm DBH, 6 with 52 cm DBH and 7 with 75 cm DBH. This is in addition to the coppice wood.

Insley (1988) made estimates of the likely yields of coppice wood in a coppice-with-standards system. Oak grown on a 20- to 35-year rotation would be expected to produce 3-7 m^3 ha^{-1} yr^{-1}, and for ash, sycamore and other hardwoods or mixed coppice on 20- to 25-year rotations, 6 – 10 m^3 ha^{-1} yr^{-1}. The preliminary yield tables for oak coppice, published by Crockford and Savill (1991), estimated that the mean annual increment to range between 2.3 and 11.1 m^3 ha^{-1} yr^{-1}, depending on site index and whether a 20-year or 35-year rotation was employed. Furthermore, Crockford and Savill (1991) concluded that mean annual increments of oak coppice would be similar to those expected from high forest plantation, but that they would occur at much earlier ages. The annual increments illustrated by Brown and Nisbit (1894) also largely concur with this assessment (see Table 8). Blythe et al. (1987) state that native broadleaves yield about 40 – 60 tonnes of air-dry wood per ha on a 20- to 25-year rotation. They calculate that 4 to 5 ha of coppice would be sufficient to supply the fuelwood needs (about 8 dry tonnes per year) in perpetuity to heat a typical house with cants 0.25 ha in size.

Decocq et al. (2004) describe the commercial management of hornbeam coppice with oak standards in France. The coppice was cut on a 30-year rotation and three quarters of the standards were also felled. The total volume extracted was approximately 200 m^3 ($\approx$ 6.7 m^3 ha^{-1} yr^{-1}), retaining at least 80, 40, 15 and 5 standards ha^{-1} of 30, 60, 90 and 120-year-old trees, respectively.

Table 8: *Average annual increment in timber crops m³ ha⁻¹ yr⁻¹ (converted from Brown and Nisbet 1894).*

Kind of tree and method of treatment	Increment per category[a] (m^3)					Age at maturity[b] (years)	
	I	II	III	IV	V	I & II	IV & V
HIGH-FOREST							
Oak	4.6 - 5.2	4.0 - 4.6	3.5 - 4.0	3.1- 3.5	2.6 - 3.3	160	120
Beech	5.2 - 5.8	4.4 - 5.0	3.8 - 4.3	3.1 - 3.8	2.6 - 3.3	(140) 120	90
Beech with spruce, etc.				4.2 - 4.6	3.8 - 4.2	…	100
Spruce	7.6 - 8.4	6.5 - 7.3	5.6 - 6.3	4.4 - 5.0	3.4 - 3.9	120	70
Scots pine	5.5 - 6.5	4.2 - 5.2	3.5 - 4.2	2.7 - 3.4	1.9 - 2.3	(120) 100	60
Birch	6.0 - 6.8	4.7 - 5.5	3.3 - 3.9	1.7 - 2.3	1.2 - 1.2	60	40
Alder	5.2 - 5.8	4.2 - 4.7	3.1 - 3.7	…	…	70	50
COPSE							
With many beech etc. in the overwood, and hardwoods as underwood	6.3 - 6.8	5.2	4.4	3.6	2.1 - 2.7	30	35
With oaks etc., as standards, and a mixture of hardwoods and softwoods as coppice	4.7	4.2	3.7	3.1	2.5	18	25
COPPICE							
Oak and hornbeam, mixed with other hardwoods and with hazel, etc.	4.8 - 5.2	4.2	3.6	2.8	1.9 - 2.1	15	20
Alders (marshy land)	6.5 - 6.9	5.5 - 5.9	4.2 - 4.7	2.7 - 3.4	1.6 - 2.1	25	35
Birches, pure or predominating	5.2 - 5.8	4.4 - 5.0	3.6 - 4.2	2.9 - 3.4	2.1 - 2.5	20	30

[a] Quality of the soil and situation relates to the suitability of the growing environment for the crop being considered, ranging from I (very good) to V (poor), and covers the productivity of the soil as well as an assessment of the existing stand on the site.

[b] Age at maturity relates to the age of economic maturity. On better classes of soil (I & II) the capital, represented by the land plus the growing stock of timber, in a high-forest will continue to show good profits for a longer time than can be yielded by poorer classes of land (IV & V). In the case of coppice, poorer classes of land require a longer rotation than more favourable classes of land to maintain the continuous productive capacity of the soil.

Advantages of coppice-with-standards

Coppice-with-standards can supply local demand for fencing material, pulpwood, fuelwood poles, charcoal, turnery wood and timber, all from one silvicultural system, because it can provide material of various sizes (Matthews 1989). The inclusion of coppicing within the system provides early returns (Troup, 1928) and since the standards are grown with their crowns entirely open, they grow very rapidly, resulting in the production of a few trees of exceptional size and value in a comparatively short time (Cheyney 1942). If ash is grown as the standard, thinnings of tellers and 2nd class standards could be used for hurleys if the butts have the required form. The cash-flow resulting from a well-managed coppice-with-standards system will be more stable than that from high forest because, in theory, identical volumes of timber of the various sizes will be harvested at the end of each coppice rotation, i.e. the same volume of tellers, 2nd class standards, 1st class standards and veterans will be harvested from one coppice rotation to the next.

Harmer et al. (2010) (see Figure 2 below) rate coppice-with-standards highly because it can provide timber, biodiversity and visual amenity benefits. From the viewpoint of nature conservation on lowland sites, coppice-with-standards is now regarded as being among the most desirable silvicultural treatments of broadleaves (Hart 1995). The standards provide a continuity of woodland conditions and a deep canopy, better protecting the soil than in the case of simple coppice (Troup 1928). Buckley and Howell (2004) reviewed the literature for sweet chestnut in England and concluded that to increase biodiversity in sweet chestnut stands, the age structure and species structure should be diversified. One method would be to introduce/maintain some standards within the stand. Some county councils in southern England (e.g. Kent and Surrey) consider traditional coppice-with-standards as the preferred management system for biodiversity in sweet chestnut (Buckley and Howell 2004). Coppice-with-standards was advocated by Towler and Barnes (1982) as the ideal management system for private woods in East Anglia. Their reasoning was that the system could fulfil the multiple objectives of woodland owners, providing a wide range of additional financial and other options, such as shooting game, farm shelter, small roundwood production for fuelwood or fencing, production of more valuable timber, landscape enhancement and wildlife conservation. Gascoigne (1980) wrote: *The growing of coppice-with-standards would in all probability be applauded by the public and planners on visual amenity grounds, would be welcomed by sporting landowners, be interesting to investors, and should silence the most telling criticism, that of the environmentalists and ecologists*. One would hope that this might be the case in Ireland. However, the coppice-with-standards system also has disadvantages compared to other more conventional silvicultural systems currently employed here.

Table 9: *Yields from some species of coppice (adapted from Begley and Coates (1961) by Harmer and Howe (2003)).*[a]

Species	Soil type	Number of stems ha^{-1} ≤ 5 cm	Number of stems ha^{-1} > 5 cm	Stools ha^{-1}	Maidens ha^{-1}	Age (yr)	Top height (m)	Yield (fresh weight t ha^{-1}) ≥ 8.75 cm	Yield (fresh weight t ha^{-1}) ≥ 5 cm	MAI (m^3 $ha^{-1}yr^{-1}$)
Site 1										
Sycamore	Sandy loam	1,275	2,500	475	50	16	12.3	47	67	
English elm				75	50					
Birch				50	100					
Site 2										
Ash	Gleyed calcareous clay	200	2,125	600	100	32	15	75	94	2.8
Birch				-	225					
Ash	Gleyed calcareous clay	500	2,300	600	450	32	13.5	102	126	3.8
Birch				-	50					
Site 3										
Oak	Sandy loam	350	1,575	425	50	37	12.6	190	216	5.1
Sweet chestnut				-	50					
Birch				-	50					
Oak	Sandy loam	200	1,425	400	25	37	13.8	155	158	3.6
Wild cherry				-	25					
Site 4										
Alder	Alkaline peat	1,425	3825	625	-	20	9.9	66	88	4.0
Birch				50	-					
Willow				25	-					
Alder	Alkaline peat	1,450	3,850	450	-	20	11.4	96	138	5.8
Birch				-	25					
Willow				25	25					

[a] Only oak was previously managed as coppice, for other coppice stools the stems were first growth from maiden stems. Yield includes maiden trees. Data for each species were from different plots on the same site. Species in bold type are the predominant species of coppice. MAI: mean annual increment.

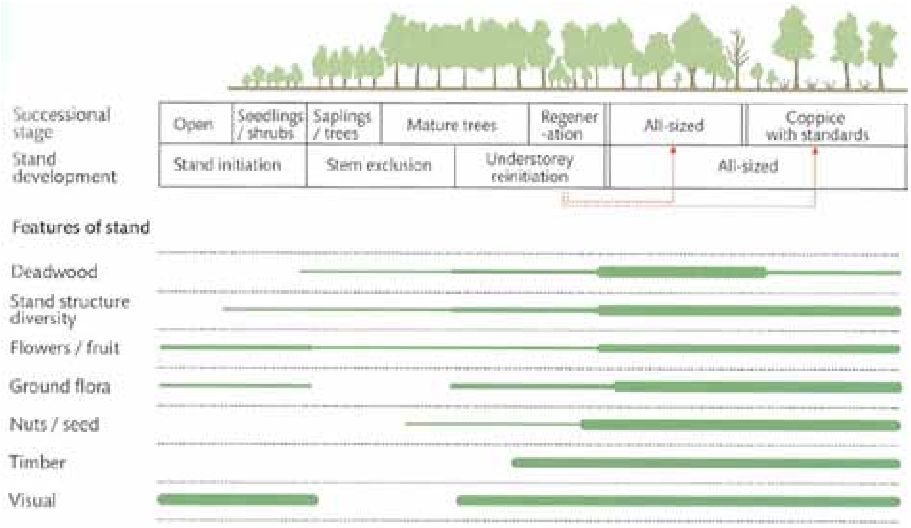

Figure 2: *Indicative relationships between stages of woodland development and relative value for a range of social, environmental and economic factors; wider bars indicate higher value. This shows general trends and does not apply to all woodland types. Adapted from Smith et al. (1997) by Harmer et al. (2010).*

Disadvantages of coppice-with-standards

Troup (1928) and Matthews (1989) both highlight the following disadvantages associated with the coppice-with-standards system:

1. The system is difficult to apply correctly. Maintaining the balance between standards and coppice and the correct distribution of standards of the different age classes is difficult. The selection of standards requires skill to implement in practice. A thick growth of coppice, which can reduce visibility, may make it more difficult to efficiently select the best quality stems in the higher canopies.
2. The standards are often more short-stemmed and branchy than trees grown in high forest, yielding a smaller proportion of clear timber. The amount of small material, including branchwood, can be approximately 75% of the total volume. Much of it will only be suitable for fuel.
3. Coppice grown under standards is generally not as vigorous as simple coppice.
4. Harvesting is more labour intensive than in high forest or simple coppice.
5. The coppice can be damaged by browsing deer. While older standards are windfirm, young standards suddenly freed from the intervening coppice are liable to be bent or uprooted by wind and snow. Smooth-barked standards may suffer from sun-scorch when exposed.

Cheyney (1942) agrees with Troup (1928) and Matthews (1989) that greater skill is required to manage coppice-with-standards correctly. However, the only other disadvantage that he provides, in comparison with simple coppice, is that a small proportion of the coppice may be suppressed by the standards. None of the above highlighted disadvantages is insurmountable, and may be of little consequence to private owners who want to manage their broadleaf stands for fuelwood and sawlog for home/farm consumption. The deleterious impact on stem form of the reserves may be improved by the use of careful selection of reserves and judicious pruning.

The potential for coppice-with-standards

The predominant product from coppice-with-standards, in terms of volume, may be firewood. The Irish market for firewood has grown by 35% over the period 2006 – 2010 with nearly 200,000 m^3 of firewood (roundwood equivalent) sold in 2010 (O'Driscoll 2011). With the current and expected future high demand for firewood, coppice-with-standards has increasingly greater potential as a multi-functional silvicultural management system in Ireland. Managed on a rotational basis, such that an area is harvested each year, the system will provide a constant cash-flow and product assortment. This will be looked upon favourably by owners.

Integrating a coppice-with-standards system within a broadleaf plantation will involve heavy thinning(s). Considering the numbers of standards presented in Table 4, achieving these numbers from a plantation planted at 1.5 – 2 m spacing may involve stumping back over 90% of the initial stems. Such an intervention may be most appropriate where the plantation quality is particularly poor. Plantation quality may be based on the number of potential crop trees (PCTs) per hectare (see Short and Radford 2008). PCTs are well-formed, vigorous, disease free stems. The application of coppice-with-standards may be best suited to plantations with fewer than 100 PCTs/ha.

The coppice-with-standards system is being trialled as a method of bringing a poorly performing pole-stage ash/oak mixture into a productive state by the B-SilvRD (Broadleaf Silviculture Research and Development) project, a 5-year COFORD-funded project. Two plots (B-SilvRD CWS1 and CWS2) have been established within a stand that was planted in 1992 in Co. Mayo and had been largely neglected since then. The original planting was 1:3 lines of ash: oak, respectively, with lines 2 m apart. Prior to intervention, the ash was in a situation resembling free-growth because the oak growth rate was poor, most likely due to suppression from the adjacent ash, and therefore there was little side competition. This may have increased the windfirmness of the ash stems relative to those growing in a monocultural situation. The stem form of the oak in the stand was also very poor (Figure 3). The best ash stems (93 stems ha^{-1} per plot) have been selected for retention as standards and the remainder felled. All the oak, except those very few stems that exhibited some potential as standards (33 and 120 stems ha^{-1} for CWS1 and CWS2 plots respectively), has been stumped back (Figure 4). It is hoped that the resultant oak coppice will exhibit greater vigour than the original planting due to the release from overhead competition, deeper and more extensive root systems and a better-developed forest soil. The conversion of the stand to coppice-with-standards may provide some flexibility for future management. If the coppice growth rate is acceptable, a decision can then be made to either single the coppice regrowth (remove all coppice regrowth except the best shoot per stool), resulting in a two-tiered high forest, or to maintain it as coppice-with-standards.

If the growth rate is unacceptable, then the coppiced area can be reconstituted via natural regeneration or it can be replanted with a suitable species to create a two-tiered high forest. Whichever choice is finally made, the end result will hopefully be an aesthetically pleasing productive mixed broadleaf stand that will become financially beneficial to the owner in later years. The stand will be managed and monitored and its potential to deliver some of these benefits will be examined in the B-SilvRD project.

Figure 3: *B-SilvRD CWS1 plot, a poorly performing stand of oak / ash mixture in Co. Mayo, prior to being converted to a coppice-with-standards system.*

Figure 4: *B-SilvRD CWS1 plot, a poorly performing stand of oak / ash mixture in Co. Mayo that has been recently converted to a coppice-with-standards system.*

Conclusions and recommendations

Coppice-with-standards was once a very common silvicultural system, but has fallen out of favour during the last two centuries, mainly due to the decreased demand for fuelwood and small dimensioned timber. However, with the recent increase in fuelwood demand, it is a system that may have greater potential once again. A considerable number of young broadleaf plantations in Ireland are currently underperforming, producing little quality sawlog timber. These forests may be suitable for conversion to this system. If the presence of 300 PCTs/ha^{-1} represents the lower limit for conventional thinning (Short and Radford 2008), then alternative silvicultural systems, which have the potential to increase crop value, need to be explored. Coppice-with-standards has the potential to:

- provide a sustainable supply of firewood and other merchantable small dimension timber; and
- vary stand structure and integrate over time a proportion of sawlog quality trees through the development of new PCTs, either by singling of coppice regrowth, natural regeneration seedlings or supplementary planting.

The B-SilvRD project is trialling the coppice-with-standards system as a means of bringing a poorly performing pole-stage broadleaf stand into productive use. The system provides some flexibility during the conversion process, so management practices can be modified depending on the success or otherwise of the coppicing. It is envisaged that the resultant stand will either be: oak and ash coppice-with-standards; two-tiered high forest with oak/ash stools singled; and/or two-tiered high forest with an underplanted/ naturally regenerated understorey. Whichever combination turns out to be the case, the future stand will hopefully be productive, sustainable, biodiverse and aesthetically pleasing. Further investigations of alternative broadleaf silvicultural systems are required, with a view to maximising the potential of poorly performing pole-stage broadleaf stands.

The main practical implications of this study are that:

- a reappraisal of the coppice-with-standards silvicultural system is warranted as it may have some potential due to the increased demand for fuelwood;
- it may also have the potential to improve poorly performing pole-stage broadleaf stands and supply a variety of products, including sawlog; and
- it will result in aesthetically pleasing, biodiverse, sustainable and productive stands.

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Recent results of growing *Eucalyptus* in Ireland

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Abstract
Interest in growing *Eucalyptus* in Ireland has increased in the last 10 years as a result of the increased demand for biomass and the projected shortages of fibre and fuel in the near future. As one of the fastest growing of the tree genera, *Eucalyptus* has the potential to supply some of these demands. Nevertheless there are a significant number of unknowns regarding the growing of *Eucalyptus*. This paper summarises the knowledge accumulated to date for this genus, as it relates to conditions in Ireland.

Keywords: *Short rotation forestry, biomass, bioenergy, fibre, panel boards, cold hardiness.*

Introduction

The current forest biomass requirements for energy on the island of Ireland have reached a level where demand exceeds supply and this gap has been forecast to increase (Phillips, 2011). It is generally accepted that this gap will not be filled from conventional forestry sources. A very fast growing, short rotation tree species is needed and some species of the genus *Eucalyptus* appear to be able to fill this need.

Although early plantings of *Eucalyptus* species in Ireland date from the mid 19th century, and despite the fact that trials of a number of species have been established for over 100 years, there is still a great deal that remains unknown about the genus and how best to grow and manage it under Irish conditions. Mooney (1960) summarised the situation in the early 1960s, which was later updated by Neilan and Thompson (2008). However, since 2008 experience in growing and utilising *Eucalyptus* material in Ireland has increased. The purpose of this paper is to summarise the results achieved, to point out the gaps in current knowledge and to highlight the potential of *Eucalyptus* as a short rotation species for Ireland.

Historical background

The rapid growth and wide variety of species (over 800) found within the genus *Eucalyptus* has attracted interest among foresters around the world since they were "discovered" in 1774. The first introductions of *Eucalyptus* species to Europe took place in the early 19th century. Most of the early material was planted in gardens and arboreta in Ireland with mixed results. One of the early surveys carried out by Elwes and Henry (1912) summarised results up to that date with the statement "If one may judge from the numerous references in horticultural literature to this genus, none has

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been more persistently tried in various parts of the country; and yet when we come to record the small number of trees which have endured our climate for more than a few years, it must be acknowledged that none has proved more disappointing." In spite of this dismal record these authors went on to discuss the performance of 12 species in the British Isles! Later Fitzpatrick (1932) listed 13 species that had grown well in Ireland. Martin (1948) summarised the survival of a range of species in the British Isles, including results from Mount Usher, Co. Wicklow, Rostrevor, Co. Down, Brook Hall, Co. Derry and Glasnevin, Co. Dublin.

Regarding its use in forestry, A.C. Forbes, who established the first experimental forestry plots of *Eucalyptus* at Avondale in 1908, concluded that *E. urnigera* (Hook. f.), *E. viminalis* (Labill), *E. muelleri* (T.B. Moore) and *E. gigantea* (name later changed to *E. delagatensis* (T.T. Bak.)) were the most promising species (Forbes, 1933). The results of a series of three species trials planted in Ballymanus property in Glenealy Forest between 1934 and 1937 have been summarised by Mooney (1960) and more recently in Neilan and Thompson (2008). These trials were later followed by a series of trial plots established throughout the country between 1925 and 1961, some of which survive today. Unfortunately much of the information about these trial plots and their performance has been lost and it is difficult to draw any clear conclusions from them.

The objective of these early trials was to produce material for sawn timber, board manufacture, pit props or transmission poles, none of which proved to be successful (Mooney 1960). Problems with splitting and cracking reduced interest in the genus and work with *Eucalyptus* essentially ended in the early 1960s. Since that time, however, *Eucalyptus* species have continued to be planted both as a landscape species as well as commercially for the production of foliage material for use in the cut flower market.

The potential for growing *Eucalyptus* in the UK has been summarised by Julian Evans in a series of papers published in the 1980s (Evans, 1980, 1983a, 1983b, and 1986). He concluded that several species (and specific provenances of some of these species) possess sufficient cold hardiness to survive in the UK. He suggested that some species should be able to produce fibre on upland sites in the UK of Yield Class 12 to 16 on a 10-year rotation. A more recent summary of UK interest in the genus is provided by Leslie et al. 2011.

In Ireland, a series of plots was established in 1993/94 of *E. nitens* ((Dean and Main.) Maid.) (not previously tested in Ireland), *E. gunnii* (Hook. f.) and *E. delagatensis*. The early results from these plots, discussed in Neilan and Thompson (2008), showed that while some of the species used earlier had good survival and growth, there were others that had a greater potential for volume production (Figure 1). While the original objective of these trials was timber production, interest has changed in recent years as a result of the unsurpassed growth rates of *Eucalyptus*. A new project began in 2008 within Coillte to "assess the potential of growing *Eucalyptus* species (particularly *E. nitens*) in Ireland for the purpose of producing fibre for use in the manufacture of panel boards and possible biomass for energy" (unpublished internal Coillte report). The project has since been expanded to include both sawn timber production and the use of *Eucalyptus* species other than *E. nitens*.

Figure 1: *An 18-year-old stand of* Eucalyptus nitens *next to one of Sitka spruce, a year older, at Cappoquin, Co. Waterford.*

The establishment results described in this paper come from a series of operational trials testing a range of species on a series of different reforestation sites in the Coillte estate, established between 2008 and 2011. All trials were planted with 25 to 30 cm containerised plants, established at 2 by 2 m spacing. The objective was to keep establishment costs (including plant costs) as low as possible, while carrying out all necessary operations for the successful establishment of the crop.

In 2008, *E. nitens* and *E. globulus* Labill (25 cm, 4 to 5 months old) plants were imported from a nursery in Spain. During the winter of 2008/09, low temperatures (-7 °C) damaged or killed most of the *E. globulus* which highlighted the fact that this species is only suitable for planting in coastal sites where temperatures are unlikely to fall below this point. As a result, the project subsequently focused on planting only *E. nitens*, which perhaps in hindsight, was a risky strategy. The winters of 2009/10 and 2010/11, with their abnormally low temperatures (-16 °C and -17 °C were recorded in January and December 2010, respectively, whereas the normal average temperatures for the same months are +4.5 °C and +5.1 °C), highlighted that, although *E. nitens* was a very productive species, it was sensitive to very cold winter temperatures. This led to a revised planting strategy in 2010 where *E. nitens* was established in low frost risk areas within 30 km of the coast (depending on the topography) and where a series of other, more cold hardy species (*E. gunnii, E. rodwayi* A.T. Baker and H.G. Sm., *E. subcrenulata* Maid. and Blakeley and several others) were established on colder, more inland sites. In addition, the strategy was modified to plant (where possible) in sites clustered close to where the material would be processed.

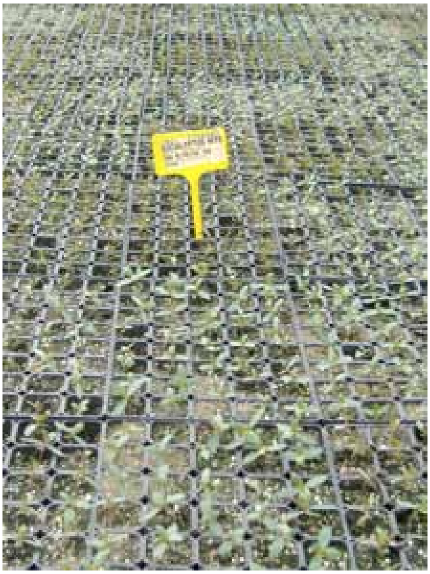

Figure 2: E. nitens *seed sown in containers and growing in a tunnel.*

Silviculture

Plant production

Because *Eucalyptus* seed is very small (about 250,000 seeds kg^{-1} of *E. nitens*) it is difficult to sow individual, or even a few seeds. Therefore, seed was either sown broadcast in seed trays and the young seedlings were transplanted into individual 100 cc cells and raised in tunnels, or it was sown directly into the cells using a precision vacuum seeder which sowed one to a few seeds per cell depending on the quality of the seed (Figure 2).

In the initial work of the Coillte 2008-2011 trials discussed above, seed was sown in containers in tunnels in early spring (February or March) with the objective to have 20 to 30 cm plants ready for field planting in May or June. The outcome of this produced soft, succulent, actively growing plants for planting, but which resulted in losses due to both mechanical damage from handling and from disease (*e.g. Botrytis*). Plants could not be held over on a site for any length of time because they were actively growing at the time of planting. This led to a change in production schedule.

In the trials established since 2009, seed was sown in containers in late spring (May to June) to produce a 25 to 30 cm plant by the end of the summer (Figure 3). Plants were grown initially in tunnels and moved out in early autumn (September) for hardening off. Plants were held in containers outdoors over winter until planting in the following spring (March to April). Dormant plants with a partly lignified stem were easier to handle than the softer actively growing plants. Timing of sowing has been shown to be critical to produce plants of the ideal size (25 to 30 cm). This size of plant is easy to handle and establishes well on reforestation sites. Larger plants are more difficult to plant and have a lower survival rate. Some species such as *E. nitens*

Figure 3: E. nitens *plants ready for field planting.*

will continue to grow in late autumn and early spring if conditions permit, so plants can be quite large (50 cm or more) at the time of planting.

Cold hardiness

The most limiting factor for *Eucalyptus* success in this country is probably low winter temperatures (Figure 4). Not only young crops, but also large trees, can be killed by low temperatures. Indeed, an 11-year-old stand of *E. nitens* near Tubbercurry in Co. Sligo in 2000 was seriously affected by a -14 °C temperature and a 16-year-old stand of E. nitens near Dundrum, Co. Tipperary in 2011 was severely damaged or killed by a temperature of ca. -15 °C. While material could be salvaged from these failures, the loss of a 3- to 4-year-old crop would be more serious because the trees would be too small to be worth harvesting.

However, cold hardiness is a complex and confusing problem to address. Published information on the cold hardiness of a species needs to be taken with some degree of caution. Often this information is not based on actual temperature measurements where the trees have been growing, but rather on meteorological station records

Figure 4: E. nitens *damaged by low temperatures in spring 2010 at Clogheen, Co. Tipperary.*

from a station some distance away. Extrapolating to field conditions based on such meteorological data is risky, perhaps providing at best some crude guidelines for where species might best be planted, but they do not provide any guarantee of success. In fact, they may provide unrealistic expectations.

Cold hardiness varies with the time of year and the temperatures the plants have previously experienced. Monthly computer controlled freezer tests were conducted between October and March on seedlings across a range of *Eucalyptus* species. In this process, 10 cm shoots were subjected to a series of target freezing temperatures (-5, -7, -9, -12, -15 and -18 °C) for 3 hours in a programmable freezer. The series of freezing temperatures were selected to bracket the range causing a 50% damage as subsequently assessed by chlorophyll fluorescence (Perks et al. 2004). Seedlings grown in tunnels, which were moved outside in September, began to increase in cold hardiness in November, became most hardy during January and February, after which they began to lose cold hardiness. Plants assessed for their cold hardiness in the winter of 2010/2011, when temperatures at the nursery reached -10 °C, became hardy to a lower temperature than the same species during the winter of 2011/2012, when the lowest temperatures at the nursery only reached -2 °C. This showed that plants varied in their hardiness from year to year depending on the date and severity of the low temperatures experienced. Indeed, in some years with mild early autumn temperatures, plants might not reach their maximum hardiness until later in the winter. This could result in early autumn frost damage. Therefore, computer controlled freezing tests provide the most accurate estimates of cold hardiness of different species at the time of outplanting.

In addition to the levels of low temperatures experienced, the duration of the period of exposure to the low temperatures, the rapidity of the temperature change and how long this low temperature persists are important in the survival of the species. The rapidity of thawing in the morning, especially under sunny conditions, may also affect the level of damage. Many publications report only the "minimum low temperature a species can survive" (usually based only on "unofficial" local measurements), which is typically the temperature a species can survive for only a short period of time. However, exposure to a warmer low temperature for a longer time can be just as damaging. For example, Evans (1983b) suggested that while some species of *Eucalyptus* he considered to be "moderately hardy" were likely to survive short periods down to -14 °C, but they could only survive long cold spells of -6 to -9 °C.

Small variations in site conditions can result in differences in survival across a site. Low lying areas tend to collect cold air (e.g. frost pockets) and may experience much lower temperatures than slightly higher positions.

In addition to differences in cold hardiness among species, there are undoubtedly differences among the various seed sources or provenances within a species. For *E. gunnii*, different provenances are commercially available including Mienna, a very cold hardy but slow growing source, and Snug, a fast growing but less cold hardy source (Graham Milligan, personal communication 2010). Unfortunately there is very little of this type of provenance information available for the species of interest for use in Irish conditions. In addition, seed of different provenances of the main species of interest are generally not available, either for testing or commercial planting.

Minimum air temperatures may also not provide enough information on their own because in their native habitat, where temperatures of -15 ºC are common, the presence of snow cover often prevents the ground from freezing. Some recovery from the base of *E. nitens* plants (whose aboveground sections had been killed) in December 2010 has been observed in Ireland, possibly because snow cover protected the roots from freezing.

Regarding cold hardiness, the main objective is to correctly assess the likely low temperatures on a given site and cautiously select species that should be able to easily tolerate the expected low temperatures. Not all sites are suitable for *Eucalyptus* and there will be some years, such as 2010, when even on good sites, extreme low-temperature events will occur and crops, both young and old, will be damaged or killed. The objective is to lengthen the odds of establishing a successful crop, by selecting the most suitable species and provenance.

Site selection

The importance of correct site selection for successful Eucalyptus establishment cannot be over emphasised. Fertile, sheltered, free draining lowland sites are best. On wet and exposed sites the potential for wind-throw needs to be considered. However, frost, freezing temperatures and perhaps soil type are the most limiting factors for *Eucalyptus* success in this country.

Soil requirements

Eucalyptus will do well on most soils with a few major exceptions. Deep peats are to be avoided. Most species prefer free draining soils and do not do well on waterlogged soils. In addition most species will not tolerate alkaline soils, although there are some species that can tolerate some soil alkalinity including *E. dalrympleana*, but most tolerant species do not grow well under our conditions.

Nutrition

Most *Eucalyptus* species originate from areas where soil nutrients are limited, particularly phosphorus and nitrogen. As a result, these species will respond to application of these nutrients, however, nutrients, especially nitrogen, may result in excessive shoot growth without complementary root growth. In the absence of any definitive studies at present, it is perhaps prudent to avoid applying any supplemental nutrition to *Eucalyptus* crops, especially nitrogen. Prudent application of low levels of phosphorus should not cause any problems and may prove to be beneficial, but further work in this area is needed.

Planting

Eucalyptus plants seem to benefit from any type of soil disturbance. Ripping if possible, is beneficial. Mounding can be also beneficial, but it increases the establishment costs which can adversely affect the economics of the crop (see section on Economic Analysis).

Figure 5: E. nitens *plantation after 2 growing seasons at Macroney, near Kilworth Co. Cork.*

Containerised plants can be planted with a dibble or spade, but it is important not to plant too deep or too shallow. If the peat plug is higher than the surrounding soil, it will lose moisture which will affect plant growth. Proper plant handling and minimum storage of plants on site before planting is necessary. Plants should not be allowed to dry out prior to planting.

Spacing

While conventional conifer silviculture in this country is based on 2,500 plants per hectare, this may be slightly higher than necessary for *Eucalyptus*. Estimates based on Irish trial results suggest that somewhere between 1,800 and 2,000 plants per hectare may be optimal for volume production, but this has not been systematically tested. Planting 2,500 plants per hectare without filling-in (unless there is exceptionally poor survival) should provide an adequately stocked stand for harvesting in 12 to 15 years. Filling in after the second full growing season will probably not be effective because of competition with the original plants, particularly if these have established well (Figure 5).

Vegetation control

Control of competing vegetation is essential for optimum *Eucalyptus* establishment and growth. *Eucalyptus* species are very sensitive to water stress and any shortage of water will inhibit growth. Failure to control vegetation will reduce growth. Competing vegetation may overtop the *Eucalyptus* and result in a delay in the establishment of the crop. Spraying a site with herbicides before planting is preferred because young *Eucalyptus* plants are susceptible to herbicide drift.

Growth and yield

Plots of *E. nitens* and *E. gunnii* around the country have provided data for the development of Irish production estimates (Figure 6). For *E. nitens* data from several of the 1992/93 plots show that an average maximum mean annual increment (MMAI) of 28 m^3 ha^{-1} yr^{-1} on a rotation length of 12 to 15 years is achievable (Table 1). This

Table 1: *Growth and yield data from three* Eucalyptus nitens *trials planted in 1993 and 1994, as well as one plot at JFK Arboretum planted in 1982*.

Trial	Age	Stems	Mean BA	Mean DBH	Stand BA	Mean vol.	Stand vol.	Top Ht.	MAI
	(years)	(ha^{-1})	(m^2ha^{-1})	cm	m^2ha^{-1}	(m^3)	(m^3ha^{-1})	(m)	($m^3ha^{-1}yr^{-1}$)
CQN3	17	1770	0.0308	19.9	54.85	0.303	543.9	22.75	32.0
CQN7	17	1206	0.0377	21.8	43.69	0.388	444.6	25.06	26.2
DDM	17	1412	0.0340	20.6	47.98	0.340	482.9	23.79	28.4
GRY	16	740	0.0460	24.2	34.04	0.560	418.0	n.a.	26.1
JFK	28	950	0.0636	28.5	60.40	0.690	656.1	31.75	23.4

CQN3- Cappoquinn stand 3
CQN7- Cappoquinn stand 7
DDM- Dundrum
JFK- John F. Kennedy Arboretum
GRY- Gorey (Red Bog)

Figure 6: E. nitens *stand at Cappoquin, Co. Waterford at 18 years-of-age*.

compares favourably with data from Australian yield tables for *Eucalyptus*. Results for *E. gunnii* suggest a MMAI of 26 m^3 ha^{-1} yr^{-1}, but these were based on a limited number of trials.

Insects, diseases and animal damage

As an introduced species in Ireland, most *Eucalyptus* species do not suffer from the insects and disease that affect their productivity in their natural habitat. However, in 2007 the larval stage of a beetle, *Paropsisterna selmani,* from Australia was found on *Eucalyptus* being grown for foliage production is south-western Ireland. The insect caused defoliation of the crop, thus reducing productivity. The insect appears to have survived recent cold winters and also appears to be spreading. Because this leaf beetle has no natural predators here it may be able to spread unimpeded. Chemical control may be practical in foliage plantations but will not be practical in forest plantations. Probably the best solution might to develop a biological control agent, such as a naturally occurring insect that is a parasite of the beetle. This method has been used successfully to control a number of introduced insects, including some that attack *Eucalyptus* (Tribe, 2003). However, it is essential that the biological control agent specifically attacks only the target insect. Work to control this pest in Ireland is urgently needed.

Different *Eucalyptus* species vary in their palatability to animals including rabbits, deer and even grey squirrels. Most are not palatable, however *E. gunnii* has proved susceptible to browsing in areas where deer or rabbit populations are high. There is no evidence to show that *Eucalyptus* species are attacked by pine weevil.

Table 2: *Comparison of height growth rates, cold hardiness and coppicing ability of a range of* Eucalyptus *species planted in Ireland.*

Species	**Growth Rates (myr^{-1})[a]**		**Cold Hardiness (°C)[b]**		**Coppicing Ability[c]**
	JFK	**UK**	**short periods**	**long periods**	
E. nitens	1.5	-	-9 to -12	-6	poor
E. gunnii	1.2	1.4 to 1.8	-18	-10 to -14	good
E. glaucescens		1.4	-16	-10 to -12	good
E. rodwayii	1.3	-	-16	-10 to -12	good
E. subcrenulata		1.2	-14	-6 to -9	good
E. coccifera	1.0	0.9 to 1.5	-16	-10 to -12	poor
E. delagatensis	1.2	-	-14	-6 to -9	
E. dalrympleana	1.3	-	-12 to -14	-6 to -9	Good to medium

[a] Based on assessments in the UK by Benson (1994) and supplemented with measurements taken at the John F. Kennedy Arboretum, New Ross, Co. Wexford.

[b] Conservative estimates of cold hardiness (where death occurs in a majority of individuals) based on recommendations from Evans (1983a and b) and personal experience of the authors.

[c] From Nichols (2008).

Figure 7: *Coppicing from a harvested* E. nitens *stump.*

Coppicing

Different species vary in their ability to produce stump sprouts and coppice (Figure 7). Table 2 provides a summary of experience in New Zealand regarding the ability of several species to coppice. Coppice offers the ability to harvest several crops without replanting, but the ability to coppice should not be the main factor in species selection. However, the ability to coppice would be valuable for the recovery of young plantations that have suffered damage due to non-lethal low temperatures, browsing and even mechanical damage.

Species

Neilan and Thompson (2008) suggested six potential species for use in Ireland, recommendations that can now be further refined. Some details on the estimated growth rate, cold hardiness and coppicing ability of several species are presented in Table 2.

E. nitens (shining gum) is probably the fastest growing species than can be grown here, but it has limited frost hardiness which resulted in large losses during the winters of 2009/10 and again in 2010/11. It is best planted in low frost-risk sites within 30 km of the coast.

E. gunnii (cider gum) provides good growth (not as fast as *E. nitens*) with good frost hardiness, but it is subject to animal browsing.

E. subcrenulata (alpine yellow gum) is closely related to *E. johnstonii* (Maid.) which has shown promise in older Irish trials (Neilan and Thompson, 2008), but it grows at higher elevations in Tasmania and thus can better tolerate low temperatures. As a result, *E. subcrenulata* has replaced *E. johnstonii* as a suggested crop species.

E. rodwayi is largely an untested species in Ireland, although a line plot of this species in the Kennedy Arboretum has performed well.

E. glaucescens (Maid. and Blakeley) (Tingiringi gum) is another species which has not been widely tested but exists in a small plot at the Kennedy Arboretum; however, it has shown potential. The main problem with establishment using this species is the limited availability of seed.

Several of the other species discussed in Neilan and Thompson (2008) are no longer considered to have any compelling reason for their use.

The *E. johnstonii* has been replaced by the more cold tolerant *E. subcrenulata*, as discussed above.

E. globulus is really only a species for sites along the coast. All plants planted in trials away from the coast in 2010 have been killed by the low winter temperatures.

E. delagatensis although having performed well in one plot planted in 1993, a seedling crop developed a fungal leaf spot disease in the autumn of 2011 which caused plant production problems.

E. urnigera and *E. viminalis* although they have grown well in the past in Ireland, have only limited frost hardiness and are not as productive as some other species.

Economic analysis

The economic returns for *E. nitens* planted on reforestation sites were calculated for a range of options. The analyses included the expected yields, over various rotation lengths and haulage distances for a range of products including pulp, pallet and saw log. The results of the analysis for pulpwood products only showed that for crops with a mean annual increment (MAI) of 28 m^3 ha^{-1} yr^{-1} or more, it was economically viable for haulage up to 70 miles and for 15-year rotations because they exceeded the 5% Return on Investment criterion. Crops with a MAI of 26 were viable for haulage distances up to 50 miles. The returns increased significantly with increasing yield and the inclusion of saw log and/or energy products, which attracted a premium price.

A rotation length of 15 years was optimum for lower yielding sites and for longer haulage distances, while 12 years was optimum for MAI's above 36 and for shorter haulage distances.

Returns for planting *E. nitens* on afforestation sites were greater than for all other species. However, they were still insufficient to justify the purchase of land at current market prices. Some form of state financial support, similar to that available for other species, would be necessary to permit the purchase of land necessary for this afforestation option.

Utilisation

Sawn timber

E. nitens logs from a 16-year-old stand in Wexford were sent to Coillte's Dundrum sawmill to test its ability to produce sawn timber (Figure 8). As expected, problems were encountered during the drying process, including splitting, cracking and distortion. Nevertheless, samples of flooring, decking and cabinetry were produced. Methods were developed in Australia that showed that these problems with *E. nitens*

Figure 8: E. nitens *rough-sawn planks at Dundrum sawmill.*

timber can be overcome and that a successful business can be developed with this product (Cannon and Innes, 2008).

Samples of Irish grown *E. nitens* timber were sent to the Centre for Timber Engineering Department at Napier University in Edinburgh for testing. The results showed that, based on the stiffness and density, this material would have difficulty meeting the D30 strength class (the lowest strength grade for hardwood timber), as defined by EN 338. In comparison with similar published measurements of Australian grown *E. nitens*, the physical and mechanical properties of the Irish grown material were inferior. As a result, a significant effort would be needed to develop a market for Irish grown *Eucalyptus* as sawn timber.

Medium Density Fibreboard (MDF)

Logs harvested from a stand of *E. nitens* in Co. Wexford were transported to the Coillte MDF mill in Clonmel, Co. Tipperary. Significant difficulties were encountered during the debarking of the logs, mainly because the equipment at the mill was designed for conifer species. The *Eucalyptus* bark, unlike conifer bark which comes off in flakes, tended to come off in long strands, which wrapped around rollers and jammed the equipment. This was a technical problem which could be solved by altering or changing the debarking equipment or procedures. For testing purposes, logs were debarked manually and used to successfully produce MDF consisting of 75% conifer and 25% *Eucalyptus*. The board produced was broadly similar to that produced from 100% conifer chips and was sold through the normal distribution chain.

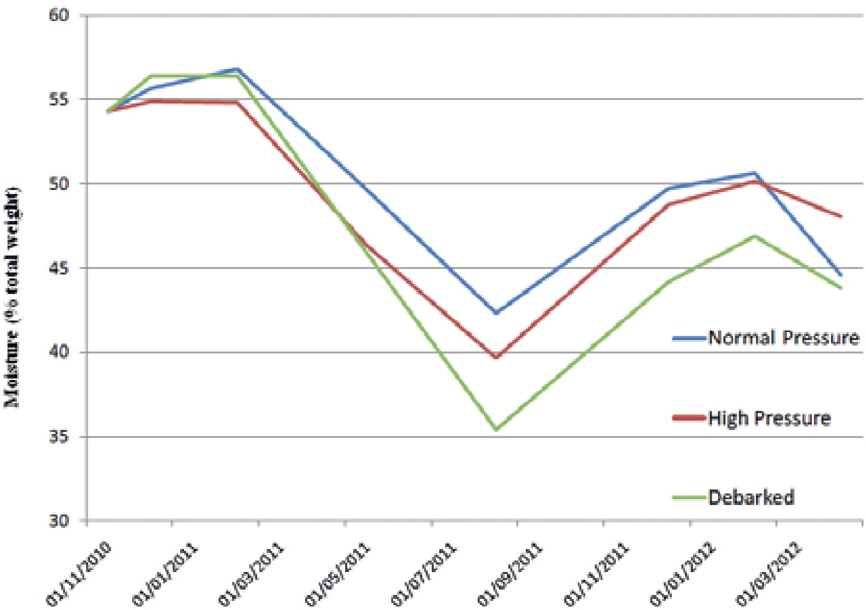

Figure 9: *Changes in moisture content of* E. nitens *logs over a 14-month period following three roller pressure treatments (Kent 2010).*

Orientated Strand Board (OSB)
Similar debarking problems were encountered at the Coillte OSB mill in Waterford. Manually debarked logs were flaked and sent to the University of North Wales where they were used to produce boards from 100% *Eucalyptus* material. This OSB board equalled or surpassed conifer boards over a range of test criteria.

Biomass for energy generation
Samples of *E. nitens* logs and lop and top were sent to the Wood Energy Research Group at the Waterford Institute of Technology for analysis. The wood density of Irish grown *E. nitens* was 435 kg m^{-3} and the bark accounted for 13% of the log weight. The gross calorific value of the round wood was 19 MJ kg^{-1} (dry weight) whereas the lop and top (leaves are known to have a high oil content) had a gross calorific value of 22.5 MJ kg^{-1}. Due mainly to the relatively higher density of its wood, the species produced 17% more energy per cubic metre than Sitka spruce.

Moisture content of wood is an important factor for both energy generation as well as fibre processing. A stand of *E. nitens* near the Coillte saw mill in Dundrum, Co. Tipperary was harvested in November 2010. Three different treatments were applied to the logs (Figure 9). The first was normal roller pressure of the harvesting head, the second was with an increased pressure of the harvesting head (to penetrate and perforate the bark to increase drying) and the third one involved manual removal of the bark. A stack of logs from each treatment was weighed periodically between

December 2010 and August 2011. Initial moisture content was 54%, which did not change between December 2010 and February 2011. By May 2011, the weight had reduced and further reductions were recorded between May 2011 and August 2011 in all treatments. In August 2011, the initial moisture content of 54% had fallen to 40% in the normal roller pressure treatment, 39% for the higher roller pressure and 35% in the debarked logs. The benefit of debarking *Eucalyptus* logs prior to processing is evident from these data.

Discussion

The results of trials of various *Eucalyptus* species over the last 100 years in Ireland have demonstrated that several species can be very productive. The main question, until very recently, was how can this material be used? Sawn timber continues to present problems, which could with time be resolved, but growing *Eucalyptus* for fibre or fuel offers the best potential end-uses at present.

There is much that is not known regarding the silvicultural management of *Eucalyptus* species in Irish conditions. Indeed some of the species and silvicultural practices discussed by Neilan and Thompson (2008) have now been revised (see above). Further information on species performance, site selection, soil and nutrient requirements, site preparation, planting stock production, vegetation control methods, spacing, rotation lengths, animal and insect damage and the ability to coppice need to be addressed.

It was, in hindsight, unwise early in the trials to concentrate entirely on one species (*E. nitens*), despite the attractiveness of the high productivity rates. The fact that *E. nitens* did not attain the level of frost hardiness necessary to survive the winters of 2009/10 and 2010/11 should not have been surprising given the failure of one of the 1994 trials of *E. nitens* in Sligo, also due to an abnormally cold period. Nevertheless, it is perhaps fortunate that this happened early on in the project, otherwise some of the more frost hardy species might not have been included in the trials.

As a result, it is prudent to have a selection of species that can cope with a range of site conditions. Certainly *E. nitens* has a place on sites with a low likelihood of frost, e.g. within 30 km of the sea. Other, more cold hardy species such as *E. gunnii* and *E. subcrenulata* can be planted on colder, more inland sites, while *E. rodwayi* and *E. glaucescens* also show potential for these sites but require further testing. Additional work is required to determine the best combination of species and location. Until this has been done, the planting of *Eucalyptus* should still be treated as experimental. Low winter temperatures, similar to the frosty and freezing conditions experienced in 2009/10 and 2010/11, can be expected to occur in the future, so caution is advised in species selection.

In addition to climatic challenges, the fact that a species of Eucalyptus leaf beetle has been found in the country could present a serious threat to these species. Because the insect has no natural pests, it could spread unhindered across the country affecting the productivity of all *Eucalyptus* species. The introduction of a natural parasite that affects only the target leaf beetle and no other organism, i.e. biological control, may be practical. This has been shown to be effective in other parts of the world, and, in fact it has already been used in Ireland to control another pest of a glaucous species of *Eucalyptus*, namely the blue gum psyllid (*Ctenarytaina eucalypti*: see Chauzat et al. 2002).

Conclusions

In spite of all these uncertainties, it appears that *Eucalyptus* can play a role in providing a source of fibre or fuel to help meet the current demands for this material in Ireland. With increased experience of *Eucalyptus* over time many of the current unknowns will be common knowledge in the future.

Practical implications

- A small number of fast growing, cold hardy *Eucalyptus* species have the potential to help bridge the gap between the forecasted supply and demand for woody biomass for energy on the island of Ireland.
- They can also be used in the production of fibre for panel board production.
- Care must be taken to match the species with the site, having regard to volume production and cold hardiness.
- More work is needed before definitive prescriptions can be given.

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A review of tree improvement programmes in Ireland – historical developments, current situation and future perspective

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Abstract
Tree breeding or tree improvement programmes have been part of Irish forestry from its early days, but it is only since the 1950s that a significant effort was made. Tree improvement programmes, in addition to providing regular sources of quality seed, provide the means of achieving further genetic gains in the productivity and quality of forest tree species. The objective of this paper is to 1) explain how tree improvement is achieved, 2) to review past programmes in both coniferous and broadleaf species, 3) to discuss the current situation in Ireland and 4) to make a case for the continuance of this important work.

Keywords: *Breeding, plus-trees, seed stands, seed orchards and propagation.*

Introduction

It has long been recognised that to ensure the success of any planting programme, a regular and continuous supply of high quality seed is vital. Only the best and most suitable material currently available should be used. Poorly adapted or low quality seed sources can result in plantation failures or substantial losses in production and in Ireland there have been some experiences of such losses. Many times in the past it was the price of seed that determined which sources were purchased and subsequently used to produce material for planting. Once a crop is established, it is difficult to remedy these problems and it should always be borne in mind that seed costs constitute only a minute proportion of the total cost of establishment.

The first opportunity to improve timber production is to carefully consider what species can be successfully grown under the local climatic conditions. Next, the most suitable seed sources or provenances for the chosen species need to be identified. Further genetic improvements can be obtained by testing and selecting individuals of the most suitable sources and crossing them with other similarly selected individuals. Finally, the best individuals from the crosses of the best parents can be selected for further breeding work (Figure 1).

Breeding is however only part of the process. The production of commercial amounts of improved material is equally important if any real benefit is to be derived from tree improvement efforts. Different levels of improvement can be achieved through seed stands, seed orchards and also through the vegetative propagation of the improved material.

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The objectives of this paper are to first provide a brief introduction into how tree improvement is accomplished, then to summarise work on tree improvement that has taken place in Ireland over the last 50 years in both coniferous and broadleaf species and finally make some observations about the current and future direction of tree improvement efforts in Ireland.

Historical developments in tree improvement

Although the breeding of plants and animals for agricultural purposes started over 10,000 years ago, the idea of breeding trees is a relatively recent one. As early as 1717, Bradley in England suggested that seed origins were important to consider in the development of forestry and this aspect would only be re-discovered later. Duhammel Du Monceau in 1760 published observations on the inheritance of properties in forest trees, but this work also went largely unnoticed. Between 1820 and 1840, Vilmorin in France established trials that showed that species of forest trees could be subdivided into climatic races (provenances) and he also produced hybrids between species of fir (*Abies* spp.). It was Cieslar in Austria who in 1904 showed that clear climatically distinct races of Norway spruce (*Picea abies* (L.) H. Karst.) were identifiable, which stimulated a renewed interest in the importance of provenance. The first modern forest tree improvement programmes began with poplar (*Populus* spp.) in the U.S.A. in the 1920s. At about the same time, the use of seed stands and seed orchards to produce improved seed were also proposed. Work on controlled crosses (crosses between two known parents) in larch (*Larix* spp.) began in Denmark in the 1930s, which served as the inspiration for other programmes that were initiated after World War II.

Historical aspects of tree improvement programmes in Ireland

One of Ireland's earliest tree breeders was Augustine Henry who published the first scientific report proving that the "Dunkeld larch" was in fact a hybrid between Japanese and European larch (*Larix kaempferi* (Lamb.) Carr. and *L. decidua* Mill.). In 1912 he began experiments to produce poplar hybrids with potential for increased growth. The first Irish provenance trial was established at Avondale in Co. Wicklow in 1916 by A.C. Forbes. Coastal and interior sources of lodgepole pine (*Pinus contorta* Douglas) were included in this trial and the results clearly demonstrated the benefit of planting coastal seed sources of this species.

Documentation of the first plus-tree surveys in Ireland can be found in a file from the 1940s containing letters signed by M.L. Anderson, the then head of the Forestry Division, which authorised Prof. Thomas Clear of University College Dublin (UCD) to carry out such a survey in state forests. However, the exact outcome of that study was not reported.

In 1951, the "Cameron Report" on the then current situation of forestry in Ireland highlighted that procuring adequate supplies of seed was one of three major difficulties facing Irish afforestation. As a result of increased demand for quality forest tree seed following the end of World War II, the Forestry Division of the Department of Lands in the early 1950s started work on securing reliable sources of good quality tree seed. Early work in Nurseries Section of the Forestry Division included the identification of seed stands, the selection of plus-trees and the establishment of seed orchards for a range of species. This material mostly originated from old state forests and some private estates. While the intentions were laudable, the programme was never adequately funded to establish seed orchards of a sufficient size and with a satisfactory number of parents to produce commercial amounts of seed. This was typical of the situation in many other countries at the time, when the idea of tree improvement was first gaining popularity.

This early work concentrated on the use of seed stands and the establishment of seed orchards of Japanese and European larch as well as Scots pine (*Pinus sylvestris* L.). Efforts were later extended to Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), beech (*Fagus sylvatica* L.) and Corsican pine (*Pinus nigra* J.F. Arnold). This material was used to establish a total of about 15 ha (37 acres) of grafted seed orchards (Anon. 1964). However, most information on this programme, including the origin of the material in these seed orchards has since been lost. Only a few small isolated remnants of the orchards remain from this early work. Nevertheless, it was a start.

With the establishment of Research Branch in the Forestry Division in 1957, a more formal series of research projects was initiated. Projects included work on eucalyptus, poplar as well as provenance trials of lodgepole pine, Scots pine, western hemlock (*Tsuga heterophyll*a (Raf.) Sarg.) and the first improvement work commenced on Sitka spruce (*Picea sitchensis* (Bong.) Carr.). Work on the development of seed orchards continued under the direction of the Nurseries Section up until 1977, when all tree improvement work was transferred to the new Genetics Section of Research Branch. Details of all this early work up until 1970 is documented in two "Forest Research Review" reports (Anon 1964, Anon 1970).

Most of the tree improvement work of the newly established Research Branch concentrated on conifers, particularly provenance studies of lodgepole pine, Sitka spruce and to a lesser extent Norway spruce, Scots pine, Douglas fir, grand fir (*Abies grandis* (Douglas ex D. Don) Lindley), noble fir (*A. procera* Rehder) and western hemlock. Seed stands of lodgepole pine, Scots pine and Corsican pine were also identified.

Soon after the establishment of a Genetics Section it was decided that a dedicated site was required to carry out the breeding and propagation work. In the 1960s, a research nursery together with a glasshouse was established at Shelton Abbey in Co. Wicklow, but pollution from the nearby fertiliser plant adversely affected the quality of plants. As a result, in the 1970s the work was first moved to Glenealy Nursery and finally to a new site at the old estate at Kilmacurra Park, Co. Wicklow. An office, potting shed, propagating tunnels and a nursery were established. Later a glasshouse, clone banks, an indoor Sitka spruce seed orchard and an outdoor Scots pine seed orchard were added. This site continues to serve as the centre of all the work in the Coillte Tree Improvement Programme.

Tree improvement work continued in the Forest Service until the establishment of Coillte Teoranta in 1989, when it was transferred to Coillte. Initially, funding for the tree improvement programme was provided by Coillte and the Forest Service, with additional funding from the European Union through a series of Research and Technology Development projects, whenever such funding was available. Over time, Forest Service funding became more limited and was directed only towards work on broadleaf species and eventually, even this funding ended. Since the mid-1990s all tree improvement work has been funded mainly by Coillte, supplemented by national (COFORD) and EU funds when available.

The establishment of the National Council for Forest Research and Development (COFORD) in 1994 emphasised the importance of forest reproductive material when it was identified as one of the five core sectoral areas, which were to be the main focus of COFORD's work (Anon. 1994). Many tree improvement projects have been funded by COFORD since its establishment.

In 2000, COFORD issued a discussion paper "Towards a strategy for gene conservation and tree improvement of broadleaved and indigenous coniferous species on the island of Ireland" which was based on the findings of a small working group comprising members from Northern Ireland and the Irish Republic (Fennessy et al. 2000). As a continuation of this work, COFORD published in 2007 "Sustaining and Developing Ireland's Forest Genetic Resources – An outline strategy" (Cahalane et al. 2007). This report was developed by a Working Group whose objective was to review the nation's forest genetic resources and it contained a number of recommendations, many of which still require implementation.

Tree improvement methods

Not all of the tree to tree variation that can be seen in a forest is due to genetic variation. Other sources of variation include environmental and developmental variation, neither of which is controlled by genes, and as a result this type of variation cannot be utilised in a breeding programme. The basis of genetic improvement lies in the fact that not all individuals within the same species are genetically identical. Most forest species are essentially wild populations, which have not been previously manipulated by man and as a result, they are genetically very variable. The best individual trees for one or more traits are chosen and used in a breeding programme to produce high quality planting stock.

Genetic improvement is permanent because the selected traits are passed on to the offspring of the selected trees. As a result genetic improvement is cumulative, so the improvements made in one generation form the basis of further improvements, which can be achieved in subsequent generations.

Tree improvement depends on utilising natural genetic variation in species and also selecting the best seed sources (provenances) of those species. In some cases, simply selecting the species or selecting the best seed source is all that is necessary to achieve the desired level of improvement. In other cases, particularly the commercially important species, it may be worthwhile to utilise additional sources of genetic variation. Additional sources of genetic variation can be utilised by:

- the selection of superior individuals (plus-trees) from the most suitable provenances;
- selection of the best families resulting from crosses between the plus-trees (superior families); and
- selection and propagation of the best individuals within these superior families (superior clones). This process is illustrated in Figure 1.

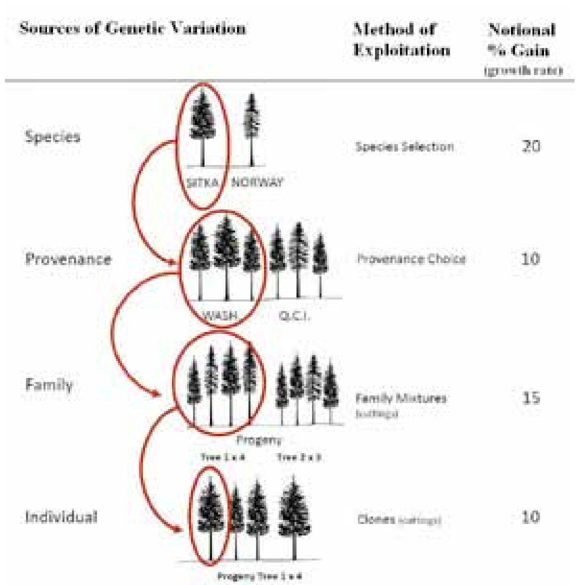

Figure 1: *Sources of variation and how they can be exploited in tree improvement.*

Whether an improvement programme stops at the selection of plus-trees or continues to selected superior clones, depends on the commercial importance of the species as well as available resource and how much time and effort is to be invested in the improvement of the species. Nevertheless, the economics for most conifer tree improvement programmes has been shown to be positive for a wide range of species. Similar results for broadleaf improvement programmes have not been established, as few evaluations have been completed. For example, Palmer et al. (1998) showed that broadleaf improvement in Britain was resulting in significant improvements, but concluded that only simple mass selection and simple recurrent selection methods could be justified. Simple mass selection yielded the highest net returns. In particular, they found that clonal techniques were difficult to justify for broadleaves, despite the higher genetic gains that can be achieved. Because of the lack of information on inheritance patterns for commercially important traits and their generally longer rotation lengths, it has been argued that appropriate silvicultural practices may provide a greater improvement in broadleaved species in a shorter period of time than classical conifer breeding techniques (Hubert and Lee, 2005).

It is also important to follow the sequence from species, to provenance, to plus-tree, to families, to clone in order to capture the greatest amount of improvement possible. Selecting what appear to be good phenotypes, regardless of parentage or provenance, will not provide maximal results from the improvement process.

In addition to selection, testing and breeding, methods for the large-scale propagation of the resulting material are important. If improved material is developed, but there is no way to produce sufficient quantities for commercial use, then the improvement work may have been wasted. Seed stands, seed orchards and vegetative propagation are critical steps which need to be considered in the production of improved material, which will be discussed in more detail below.

Species trials

Because of the limited number of native forest tree species in this country exotic species, particularly the early introductions,, played an important commercial role. Sycamore (*Acer pseudoplatanus* L.) and beech were among the first species to be introduced, although exactly when this happened is uncertain. Augustine Henry's submission to the 1908 Departmental Committee Report on Irish Forestry, made the case for considering introduced species to help re-establish forests in Ireland. A.C. Forbes, when establishing the trial/demonstration plots at Avondale, aimed to "….rightly or wrongly turn it (Avondale) into a forest experimental station along the lines of a continental forest garden…", "…as a demonstration and experimental area, which might prove of service not only for educational and training purposes, but as one which tree planters throughout Ireland could inspect at any time." In addition, species that survived and prospered in private gardens and arboreta, might also become potential forest species. The first Sitka spruce planted in Ireland was on the Curraghmore Estate in Co. Waterford in the early 1830s. Because this planting showed great promise, the first trial plantations were established in the 1870s and 1880s and by the 1920s it was already beginning to become an important commercial species in Ireland.

The Research Branch of the Forest and Wildlife Service established a series of species trials between 1958 and 1965 across a range of site types. However, the main conclusion from these trials was that Sitka spruce and lodgepole pine were the best suited and most adapted introduced species for the majority of site types available for afforestation in Ireland.

Provenance testing

Once a potential species has been identified, the question then becomes which are the most suitable sources of seed (provenances) to grow under Irish climatic conditions? Provenance testing is the initial phase of most tree improvement programmes. Seed is collected from known locations throughout the natural range of the species and tested in the new location on a variety of sites where it could be commercially planted. By their very nature, provenance trials tend to involve an extensive seed collection programme, followed by production of the plants, their establishment in scientifically designed field trials and their maintenance and assessment after a suitable period of time. For most species one quarter to one third of the rotation length of the species is required to provide meaningful performance results. For relatively fast growing coniferous species such as Sitka spruce, this means between 10 and 15 years, whereas for broadleaved species, this can require 17 to 33 years for species with a 70- to 100-year rotation length.

Most of the provenance trials of non-native conifers in Ireland were organised through the International Union of Forest Research Organisations (IUFRO). While this organisation does not fund provenance trial work, it facilitates international collaboration in the collection and distribution of reproductive material as well as the exchange of results. Without such an organisation, it is doubtful whether most of the large international provenance trials would have been possible. IUFRO provenance trials have been established in this country for a number of important species including Sitka spruce, lodgepole pine, Douglas fir, Norway spruce, grand fir, noble fir, Japanese larch, Japanese cedar (*Cryptomeria japonica* (L.f.) D. Don), Monterey pine (*Pinus radiata* D. Don), Bishop pine (*Pinus muricata* D. Don), Pacific silver fir (*A. amabilis* Douglas ex J. Forbes) and oak (*Quercus* spp.). In addition, several EU funded programmes have also allowed the exchange of material for provenance testing, particularly of broadleaved species.

Results from provenance trials identify the most suitable seed sources for this country and provided the basis of the "recommended seed sources" for the Forest Service grant aided planting programme (Pfeifer and Thompson 1994). However, it is perhaps also just as important to know which seed sources are unsuitable, so that they can be avoided.

In addition to international trials, in cases where native species are to be re-established, it may be worthwhile to try to identify the most suitable native seed sources. Specifically, in Ireland this has led to trials of Irish ash, oak and birch. In most cases, this material was also compared with international sources as controls.

Plus-tree selection and testing

In order to breed superior trees, it is necessary to have known superior parents in the breeding programme. This involves the selection of phenotypically superior individuals, which are known as plus-trees. An example of some of the traits used to select a phenotypically superior broadleaf are described in Figure 2. Because the appearance of an individual, or its phenotype, is the result of the interaction of the genes in the individual and the environment in which it is growing, it is necessary to ascertain that the superior phenotype is due to genetic rather than environmental factors. This is accomplished by collecting seed from the plus-tree, growing seedlings and planting them on a range of environmentally different sites, where they would be expected to be grown. These are known as progeny tests because the offspring or the progeny are being tested, rather than the plus-tree itself directly. After a suitable period of time (again about a quarter to one third of the species rotation length), individuals that are superior due to genetic rather than environmental factors can be identified based on the performance of their progeny across a range of different growing environments.

It is essential to reselect only the best plus-trees for a breeding programme, which typically means that only the top 10 to 15% of the selected plus-trees progress; the rest are usually discarded. As a result, a population of 200 or more plus-trees is necessary to provide a minimal breeding population of more than 20 selected plus-trees. Therefore, it is essential to select a sufficient number of plus-trees to begin a tree improvement programme. Relaxing the selection intensity at this early stage can only result in a lowering of the final level of genetic improvement achieved from the breeding programme.

Seed orchards may be established with phenotypically selected individuals but the

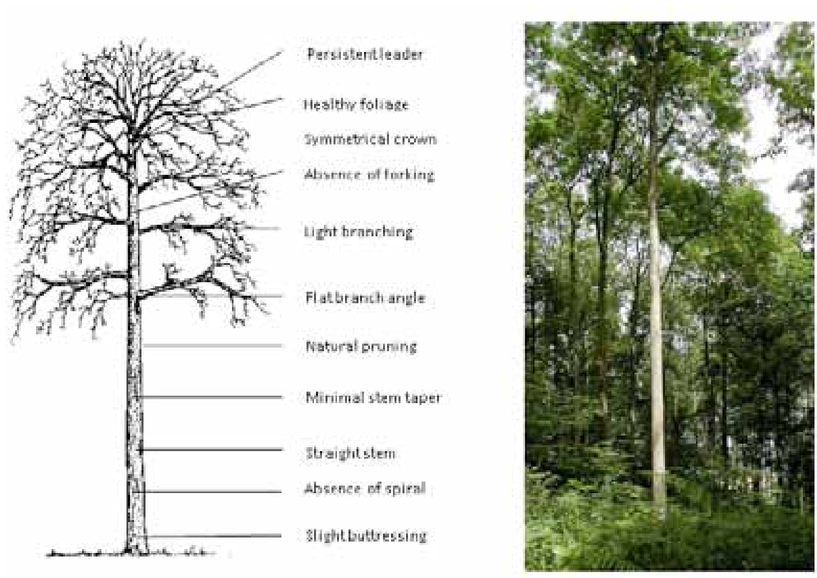

Figure 2: *Possible selection characteristics of a broadleaf plus-tree. Diagram from Future Trees Trust and photograph courtesy of Jo Clark.*

performance of the offspring is not evaluated, resulting in an untested seed orchard. Therefore, the improvement in productivity and quality achieved over seed collected from wild stands cannot be calculated. However, progeny testing the phenotypically selected individuals and the use of only the best in the seed orchard, results in a tested seed orchard which produces seed of a higher productivity and quality. Testing of material takes time, is costly and is usually only undertaken with already commercially important species.

Specific crosses and selection of superior individuals

Just as there are genetically superior parents, there are also certain specific combinations of genes that result in above average progeny. While these good crosses may occur randomly in seed orchards, they are usually lost when mixed with results of many other good, but variable, crosses. Results of crosses between two specific parents are known as full-sibling crosses because the offspring have both parents in common. The resulting individuals will be approximately equal to the average of the performance of their parents. The planting of this type of material is called family forestry or full-sib forestry because all the individuals in the plantation have the same two parents in common.

When two selected parents are crossed, the resulting offspring are not all genetically identical. As a result, some individuals are better than others within a cross and by selecting the best individual or a small number of individuals from a particular cross, further genetic improvement can be captured. These selected individuals can be propagated as clones because they exist as a single selected individual, which can then be reproduced using methods known as vegetative propagation (grafting, layering, rooting of cuttings or tissue culture).

Only for the most important species should selected crosses or clones be considered because of the time and costs involved. Nevertheless, the use of selected and tested clones can significantly increase the quality and productivity of the planting stock.

Propagation methods

Seed stands

Seed stands are a simple way to provide material from the most suitable seed sources. Once a suitable source of seed has been identified, the next step is to produce enough seed of this source for commercial use. Seed stands can either be specifically established new stands or they can be selected from existing stands of the most suitable sources. They are selected based on a set of criteria that include provenance, location, volume production, stand quality, health, size and age. Such stands are managed mainly for seed production and collection, with timber production a secondary objective (Fennessy 1994).

Since Ireland joined the EU in 1967, many stands have been registered under the National Catalogue of Seed Stands. However in most cases, when those stands reached maturity, they were clear-felled and replaced with new stands. This process continues and at the end of 2011, 344 stands covering 21 species, with a total area of 4,290 ha, are currently classified as seed stands (Table 1).

Seed orchards

Seed orchards, as discussed earlier, are plantations of selected superior (untested or tested) individuals, which are brought together to breed and produce seed, which combines the best selected traits of the parents. Seed orchards are expensive to establish, require more than normal maintenance, have a limited lifespan and are not easy to improve the genetic quality of the seed they produce once they have been established. In spite of this, for many species around the world, seed orchards provide the major source of improved seed.

Seed processing

While good sources of seed are required, it is also necessary to have facilities to extract, clean and store the seed. In the 1930s, a simple kiln was built at Avondale Co. Wicklow, for the extraction of seed from harvested cones. This facility was later updated, however, in latter years it was deemed more efficient to have all seed processed in the UK. In the 1980s, Ireland was the only country in the EU without its own forest tree seed processing facility. However, the rapid expansion of forestry in the early 1990s highlighted the need to have a national facility which led to the establishment of the National Seed Centre at Ballintemple Nursery in Co. Carlow. This modern seed processing facility was funded in part by the Forest Service. The objective was to meet Ireland's needs regarding the provision of a continuous supply of the most suitable sources of reproductive material.

Table 1: *Total area of seed stands by species, correct as of 31st December 2011.*

	Number of stands	Area (ha)
Broadleaves		
Sessile oak	44	1381.3
Pedunculate oak	44	780.0
Ash	8	155.8
Alder	11	113.3
Beech	18	80.3
Birch	6	26.0
Sweet chestnut	3	8.6
Sycamore	4	7.0
Conifers		
Sitka spruce	74	610.9
Norway spruce	35	347.3
Douglas fir	19	203.6
Scots pine	19	158.2
Lodgepole pine	15	138.1
Japanese larch	16	68.7
Corsican pine	2	63.1
Yew	3	33.1
Monterey pine	9	21.7
European larch	4	19.7
Western red cedar	5	14.9
Lawson’s cypress	1	3.3
Hybrid larch	1	2.9
Mixed species stands	3	52.8

Vegetative propagation

Among the several methods of vegetative propagation that are available for forest trees, only two have the potential for large-scale application: (i) rooted cuttings and (ii) a type of tissue culture propagation known as somatic embryogenesis. Both allow for the large-scale multiplication of selected individuals, but because both methods require significant amounts of handling, the costs associated with producing material is higher than that of seedling material. However, the higher per plant costs can be more than offset by the increased productivity of this highly selected material (Philips and Thompson 2010).

Somatic embryogenesis is a method of vegetative propagation, whereby a single selected individual is multiplied under laboratory conditions to produce a theoretically unlimited number of copies of the original individual. Material from full-sib crosses of tested parents are used to produce an embryogenic cell line, which is then used to produce a number of stock plants. These stock plants are planted as hedges, which produce cuttings (up to 50 cuttings per year for 5 to 7 years) that are rooted and the resulting plants are used to establish new plantations of improved material. In this way, the high cost of the somatic embryo stock plant is spread over several hundred rooted cuttings over time, thus greatly reducing unit costs.

Tree improvement programmes in Ireland - conifers

Lodgepole pine

State forestry commenced operations in 1904 but by the mid 1950s, a number of issues in relation to the performance of some species had arisen. Lodgepole pine had proved to be inconsistent in its performance due to variations in the genetic quality of the seed. As knowledge on suitable seed sources for Ireland was non-existent at the time, seed was procured on a tender basis, with the cheapest usually being purchased. As a result significant quantities of unsuitable origins were imported (e.g. Lulu Island), which subsequently formed poor and underperforming crops.

Provenance trials, however, were established in 1965, 1966, 1967, each consisting of a limited number of provenances. In 1972 the establishment of the IUFRO lodgepole pine provenance trial testing a total of 58 seed sources from Alaska to California, provided definitive information on the most suitable seed sources for Irish conditions. The dilemma with lodgepole pine was whether to select fast growing, unstable and poor stem form from south coastal sources (Washington and Oregon), or to select a slower growing, stable and better stem form from north coastal sources (British Columbia, Canada). Ultimately, the better vigour of south coastal sources was favoured over the superior stem form and stability of the North coastal sources. For a detailed summary of the results of provenance trials of lodgepole pine in Ireland, see Thompson et al. 2003.

Plus-tree selection of lodgepole began in 1961, with 332 plus-trees being selected in total. Most of these were progeny tested and a total of 171 were re-selected based on their performance in these trials. They were then included in four seed orchards.

Unfortunately, due to continuing problems with poor stem form and instability, the planting of lodgepole pine declined rapidly from peaks in the 1960s and 1970s to very low levels in the 1980s. As a result, the seed orchards were left unmanaged for so long that they now no longer produce any significant seed crops. However, with increased harvesting of lodgepole pine stands in the west in recent years, the demand for lodgepole pine seed has increased, but obtaining suitable seed has become very difficult. Work to regenerate these orchards has now commenced with the recent re-grafting of material from the former lodgepole pine seed orchards. This is also a way to conserve as many of the earlier selected parents as possible.

A novel way to combine the fast growth of the South coastal material with the good stem form and stability of the North coastal sources was to hybridize these two sources in what are known as interprovenance hybrids (Thompson et al. 2003). Some of these hybrids do in fact combine the rapid growth of the South coastal material, with the improved stem form and stability of the North coastal sources. In the UK, seed orchards designed to produce this material were established, but at about the same time demand for lodgepole pine also declined in the UK and these orchards were also allowed to go unmanaged, so they no longer produce seed crops either. However, scion material was obtained from Forest Research in Scotland and has been grafted to establish a new series of interprovenance hybrid seed orchards in this country, but it will take a number of years before this material will be available in commercial amounts.

Sitka spruce

With the decline of the lodgepole pine planting programme, demand switched to Sitka spruce and in the early 1970s an improvement programme commenced. The first Sitka spruce provenance trial was planted in 1960 with a limited number of provenances. Nevertheless, early results suggested that the more southern sources (Washington and Oregon) were more suitable than from northerly sources (Queen Charlotte Islands). This was confirmed by the results of the IUFRO Sitka spruce provenance trial series planted in 1975. The results of the provenance work on Sitka spruce is discussed in Thompson et al. 2005.

The original objective of the Sitka Spruce Improvement Programme was to select and test 1,000 superior trees (plus-trees) with the objective of identifying approximately 100 selected individuals, which would form the basis of a Sitka Spruce breeding programme. Only about 750 plus-trees were selected for a variety of reasons, and the progeny of about 550 of these plus-trees were tested. Selecting parents that would provide a 15% or more increase in height growth relative to unimproved material, combined with a similar improvement in stem form, resulted in the re-selection of 86 plus-trees (16% of the original 550 parents). Then wood quality was considered; parent trees were maintained in the programme only if the result showed no significant loss in wood density, which resulted in the selection of a total of 40 plus-trees from the original 550 plus-trees (7%). This formed the first stage of the selection and breeding programme.

Sitka spruce is not a regular seed producer under Irish climatic conditions, so seed orchards were not considered to be a feasible production strategy. As a result, alternative plant production methods were explored. Fortunately, branch cuttings from young Sitka spruce plants root well, so a vegetative propagation programme was initiated. In this way, small amounts of seed (or plants produced by somatic embryogenesis) resulting from superior crosses can be used to grow stock plants, which produce cuttings for rooting which are eventually planted in the field. This is carried out commercially at the Coillte nursery at Clone near Aughrim in Co. Wicklow. This facility produces a "bulk mix" of material representing a very diverse range of genetic material.

The objective of the current breeding programme is to identify the best full-sib crosses and to use this material to generate stock plants for the vegetative propagation programme. The first full-sib progeny trials have been established and the first results are now becoming available. Preliminary results demonstrate that further improvements are possible by planting the best full-sib crosses. In addition, trials have also been established to determine the level of further improvement possible from selecting the best individuals within the best full-sib crosses.

Monterey pine
A third conifer species, Monterey pine, gained some prominence in the late 1970s and was the subject of an improvement programme starting in 1979. This species has shown promise in plantations, but it tended to suffer from what is known as the "yellows," which is a fungal needle disease. This disease caused the loss of all but the current year needles, thus reducing the photosynthetic area and consequently productivity. Individuals can be selected with resistance to this disease and the improvement programme was designed to select fast growing healthy individuals, which did not suffer from the yellows problem.

In total, 456 plus-trees were selected and several progeny and clonal tests were established before the programme was terminated in 1985. A provenance trail with mainland and island populations showed that material from Guadalupe showed good resistance to the "yellows" under Irish conditions.

Other coniferous species
Over the years there has always been a high level of cooperation between Irish and British scientists working in the area of tree improvement. Material selected by the Tree Improvement Branch of the British Forestry Commission was made available to Ireland in the 1980s. This included tested Scots pine and a hybrid larch clones which were used to establish seed orchards. The hybrid larch orchard has never been very productive, but the Scots pine orchard continues to be very productive, even after 30 years. In addition, a seed orchard based on selected individuals from a high quality Irish Scots pine stand at Killballyboy in Clogheen forest is also currently in production. Currently, all Scots pine planted in Ireland originates from these two seed orchards.

Provenance testing work with noble fir was originally designed to select material for timber production, but later it was expanded to include the identification of seed sources suitable for Christmas tree production. In 1996, a particularly good cone crop in Irish stands of noble fir was exploited to provide material for the establishment of a provenance trial, funded by COFORD. Several imported seed sources were also included in this trial. Differences were found between provenances in survival rates, height growth, stem form, leader status, crown symmetry, crown density, foliage colour and several other traits important in the production of quality Christmas trees (Thompson 2005). In 2004, seed was obtained from what are considered some of the best Danish seed sources of noble fir seed. The seed was used to establish a provenance trial in Ireland. The results of the assessments carried out after five years in the field are currently being evaluated.

For most of the conifer species, with the exception of Sitka spruce and lodgepole pine, work beyond the identification of the most suitable seed sources has not been considered necessary. The low number of seedlings of these species currently being planted makes the long-term investment in further breeding work (e.g. the selection of superior parents and individuals) uneconomic for these species. In addition, for some species tree improvement programmes in other parts of the world may have already developed improved material based on the provenances best suited to Irish conditions. Douglas fir from ongoing breeding programmes in Oregon and Washington and hybrid larch breeding programmes in Europe are examples of this kind of material. It is more cost-effective to purchase material from these programmes, rather than duplicating these efforts.

Tree improvement programmes in Ireland - broadleaves

Work with broadleaf improvement began with the establishment of the Avondale plots in the early 1900s. Improvement work by the Nursery Section of the Forestry Division in the 1950s began with beech and was later extended to silver and downy birch (*Betula pendula* Roth and *B. pubescens* Ehrh.), ash (*Fraxinus excelsior* L.), sycamore and aspen (*Populus tremula* L.). Initially Research Branch work was undertaken with poplar clones and red oak (*Quercus borealis* Michx.), as well as continuing work on *Eucalyptus* spp. that had begun in the 1930s (Mooney 1960). Improvement work was later extended to southern beech (*Nothofagus* spp.).

Interest in oak improvement was stimulated by a good acorn crop in 1987. Work was undertaken to test different native Irish oak stands (Felton et al. 2006, Felton and Thompson 2008). At about the same time, an IUFRO provenance collection of oak including material from Ireland, the UK, France, the Netherlands and Germany was established in Clonegal Forest in Co. Wexford (Lally and Thompson 2000). Subsequently, trials were established to test further sources of oak, as well as ash and cherry.

In 1991, Coillte participated in an EU funded project under the ÉCLAIR programme to collect and propagate valuable broadleaf material. This programme allowed for the selection and propagation of phenotypically selected oak, ash, sycamore and cherry in the Coillte estate, along with an exchange of material with other partner countries. The work continued after the project ended in 1994 with funding from the Forest Service. In total about 100 selected individuals of oak, ash and sycamore and about 50 of cherry, were selected and used to establish a series of gene banks (Figure 3).

As a result of these selections, a number of untested clonal seed orchards were established in a former nursery site near Ballyhea, Co. Cork (Figure 4). To date, an area of approximately 20 ha is dedicated to a National Broadleaf Seed Orchard. This dedicated orchard area now includes an untested ash clonal orchard, planted in 2003 and based on material selected under the ÉCLAIR Programme, as well as a further similarly untested ash clonal seed orchard of 3.5 ha that was established in 2006. In 2003, a small (0.5 ha) untested sycamore clonal seed orchard was established at the site, also using material selected under the ÉCLAIR programme.

In 1995 and 1997, Coillte participated in a project to establish a set of provenance trials with beech across Europe. In total 21 trials were established consisting of 34 provenances collected from the UK and Ireland in the west, to Romania in the east, Sweden in the north and as far as Italy in the south. This trial will provide information on the best Irish or UK beech seed sources for use in Ireland, as well as information

Figure 3: *An ash clone bank at Kilmacurra, Co. Wicklow.*

Figure 4: *A broadleaf seed orchard at Rathluirc, Co. Cork.*

on unsuitable seed sources that should be avoided during years in which there is insufficient seed available from Irish or UK stands (Thompson 2007).

In 2001, an EU project (RAP; Realising Ash's Potential) provided funding for the collection and exchange of material to establish a series of ash provenance trials at European level. Coillte established one trial of this material consisting of 48 seed sources from Britain and Ireland in the west to Poland in the east and Italy to the south. A detailed assessment was carried out in 2011 (after six years growth), but this is only a preliminary assessment of performance. More meaningful results are expected to emerge after about 15 to 20 years.

Teagasc commenced work on birch in 2004, with a pilot study for the improvement of Irish birch funded by COFORD (O'Dowd 2004). An outcome of this programme was the development of a small (0.5 ha.) untested seedling seed orchard in Rathluirc and an indoor seed orchard in the Teagasc Research Station at Kinsealy. In 2009/10 the first commercial quantity of improved birch seed became available from this indoor seed orchard and was sown in 2011. This seed will produce the first commercial crop of plants from the programme in autumn 2012.

In 2004 a small untested alder seedling seed orchard composed of selected Irish material and 0.5 ha in extent was establish in Rathluirc and this orchard was thinned in 2011 (Figure 5).

More recently interest in *Eucalyptus* has redeveloped due to the species rapid growth rates and its ability to provide both fibre and fuel for biomass projects (Nielan and Thompson 2008). Work at present is mainly aimed at the identification of the most suitable species for use under Irish conditions and where they can be successfully grown.

Figure 5: *An alder seed stand at Rathluirc following a first thinning.*

Future Trees Trust
As the broadleaf element of our afforestation programme expands, the need to improve quality becomes paramount. Over the past 21 years, a similar move has taken place in Britain with the establishment of the British Hardwoods Improvement Programme (BHIP) to improve the quality and productivity of broadleaved woodlands. Since 1998, BHIP fully incorporated Ireland into its activities as the British and Irish Hardwoods Improvement Programme (BIHIP), now known as the Future Trees Trust. This programme is a voluntary association of landowners, research workers and professional foresters, who have an interest and determination to improve the quality and productivity of seven broadleaf species with the potential to produce valuable commercial timber crops, namely oak, ash, birch, cherry, sweet chestnut, sycamore and walnut. Separate sub-programmes are in progress for each of the seven species and these are expected to increase the proportion of timber volume recoverable through practical selection and breeding programmes. This includes an oak seedling seed orchard of approximately 2.5 ha, which was established in 2003 in Rathluirc and is one of a series of eight such orchards established throughout the UK and Ireland and coordinated by Future Trees Trust.

Current developments in tree improvement
In 2007, COFORD assembled a small group of experts to prepare a strategy for managing Ireland's forest genetic resources (Cahalane et al. 2007). This report provided a series of recommendations which include:

- adoption of the proposed strategy as the basis for a national programme;
- the establishment of a National Forest Genetics Advisory Group to manage this resource; and
- the establishment of a prioritised long-term funded research and development programme for forest genetic resources.

In late 2010, a number of calls for proposals were launched by the Department of Agriculture, Fisheries and Food under the COFORD programme, which included work on Forest Genetic Resources. This call was directly based on the list of research priorities presented in the 2007 strategy. A new four-year programme, "ForGen" was awarded to a team co-ordinated by UCD Forestry of the School of Agriculture and Food Science in late 2011, which also includes the UCD School of Biology and Environmental Science, the Botanic Gardens, and Teagasc, with Coillte as a subcontractor to UCD. The programme will include work on the following subjects:

- Broadleaves
  - Setting priorities for species improvement programmes;
  - Completing provenance work;
  - Development of improved material.
- Sitka spruce
  - Continued development of the breeding programme;
  - Developing improved material for mass production;
  - Developing clonal varieties;

Demonstrating the potential of family block (full-sib) plantings;
Commencement of the second and further generation improvement programmes.

- Vegetative Propagation
  Further development of micropropagation systems.
- Developing Breeding Tools
  Improving flower induction techniques;
  Improving cryogenic storage systems;
  Developing early selection and testing methods;
  Improving methods to predict seed crops;
  Consideration of the effect of climate change on forest genetic resources;
  Prioritisation of species in breeding programmes though a cost-benefit analysis.
- Developing a National Gene Conservation Strategy
  Conduct a critical review of existing forest genetic resources;
  Prioritise species for conservation;
  Identify infrastructural gaps;
  Provide recommendations on how this strategy could be implemented.

The ForGen programme is a welcome stimulus to tree improvement efforts in this country. However, it is uncertain as to what will happen to the area after the project ends in 2015.

Conclusions

Significant progress has been made in the genetic improvement of many of the species used in Irish forestry over the last 50 years. Information from provenance trials has been used as the basis of seed source recommendations and tree breeding work has produced genetically improved planting stock for certain species. However, it is essential that the valuable genetic material from this effort be protected, especially during these current difficult economic times. Considerable resources have gone into the development of this material and it would be costly to have to duplicate these efforts again. An example of this is evident from experience in the lodgepole pine improvement programme, which was discontinued in the 1980s. While some valuable material was lost, enough survived to provide the basis for a series of new seed orchards.

It is relatively simple to identify phenotypically selected plus-trees, but this is only the start of any improvement work. It needs to be appreciated that a considerable amount of time and money must be invested to achieve significant genetic improvements in a species. Without progeny testing of an adequate number of individuals from which to select the best parent trees (discarding 80 to 90% of selections), the level of improvement will be very limited. Progeny testing requires an investment of both time and money, particularly for broadleaved species.

As has been suggested by Hubert and Lee (2005), applying the conifer tree improvement model of plus-tree selection, progeny testing followed by the establishment of grafted seed orchards, while successful with commercially important conifer species, may not be as successful with broadleaf species. With broadleaf species, conventional silvicultural practices can have just as much effect on quality as breeding, but without the investment in time and money required in a tree breeding programme. Therefore, before a tree improvement programme is undertaken, a realistic review of the time, resources and level of commitment is required.

A long-term commitment to a national tree improvement programme needs to be made as highlighted by Savill et al. (2005). Tree improvement programmes, especially those for broadleaves, have suffered from inadequate and sporadic investment. There has been a lack of target setting, long term commitment and sometimes use of inappropriate methodologies. Most funding opportunities for tree improvement programmes depend on short (three- to five-year) funding periods, during which it is very difficult to make any significant progress unless work is already underway. Even so, frequently work on a particular species ends, or at least becomes dormant, when funding ends. To overcome this dilemma, some countries have established successful cooperative tree improvement programmes. Unfortunately in Ireland, the number of potential members would be quite small. Nevertheless, if tree improvement work is to continue and make significant progress, some form of stable long-term funding commitment is needed which is best provided at national level. This would include the maintenance of facilities, genetic collections, the ability to establish, maintain and assess field trials (as well as the presence of trained personnel to carry out this work) are all essential for such work to continue. Unless this is recognised, together with an acknowledgement of the importance of the protection of the forest genetic resource, as presented in the 2007 COFORD forest genetic resources strategy, considerable investment in time, effort and resources will have been wasted, with potentially serious consequences for forestry in Ireland.

Practical considerations

The following is a list of actions that need to be undertaken to ensure that tree improvement work continues in this country:

1. The proposed national strategy for forest genetic resources (Cahalane et al. 2007) needs to be adopted, including the establishment of a National Forest Genetic Resources Advisory Group.
2. A national long-term commitment to tree improvement requirements is needed to maintain the infrastructure and provide trained personnel to carry out this work.
3. A programme to promote the use of the most suitable genetic material needs to be developed and implemented.
4. A programme of prioritisation of species for tree improvement (which will be developed in the COFORD funded *ForGen* project) needs to be implemented.
5. The influence of climate change on species and provenance selection (which will be explored under the *ForGen* project) needs to be implemented.

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The Forests of Atlantic Europe

EFIATLANTIC, a regional office of the European Forest Institute is based in Bordeaux. It seeks to promote the interests of forest research organisations and universities in the Atlantic region of Europe, from Scotland to northern Portugal. It does this through networking, coordination of research, advocacy and communication. Throughout the region, there is a focus on plantation forestry.

This is the first in a series of articles on forestry in Atlantic Europe. While production is the primary management objective throughout the region, forests are used for a variety of purposes. This article deals with the forests of coastal dunes in France and Portugal.

Maritime pine (*Pinus pinaster*) forest, Département des Landes, Aquitaine, France.

Forests of soft coasts

Edward P. Farrell[a*]

Abstract
For centuries, forests have been established on coastal dunes in an effort to stabilise shifting sands which were making habitation of coastal areas difficult, if not impossible. The greatest area of coastal dunes in Europe is in Aquitaine, in south-west France. The paper describes techniques developed in the 19th century to stabilise mobile dunes and the contribution played by dune forests in the process. The practice developed in Aquitaine has been taken up in many other countries. Forests continue to play a role in dune stabilisation, but in a more site-specific manner, with greater concern for the conservation of the dune ecosystem. Over two centuries, the primary function of the coastal dune forests of south-west France has changed from coastal protection, to resin production, to wood production and in recent decades, to recreation.

Keywords: *Coastal forests, dune stabilisation, Aquitaine, the Landes, maritime pine.*

Shifting dunes – a threat to coastal communities

The coastal dunes of the Atlantic Biogeographical Region are the most important dune systems in Europe (Houston 2005). Large dune systems occur on the west coast of Denmark, in Ireland and Scotland and in the Netherlands, but the most extensive are in south-west France, in the Bay of Biscay, on the coast of Aquitaine. Mobile dunes have presented a serious threat to coastal communities over many centuries. Forests have played and continue to play, an important role in the stabilisation of shifting sands.

Dunes have traditionally been used for a variety of purposes including sand extraction, cutting of dune grasses, cultivation and grazing. With proper management, most of these activities can be sustained but unregulated exploitation has often contributed to destabilisation (Blanchard 1926, Houston 2005). Mobile dunes and the subsequent sand invasion of farmland and villages were common problems for many centuries, not only in Aquitaine, but also in Brittany as well as Denmark, Scotland and Ireland. Houses, farms and even whole villages were buried. However, due to their poverty, the inhabitants of these regions could not survive without the grazing and the fuel, or the thatching material which the dunes provided, thus exacerbating the problem.

In the west of Ireland, shifting sands were responsible for the destruction of pasture land and burying villages (Kinahan and McHenry 1882). It is interesting to note that a stand of maritime pine, from seed imported from Bordeaux, was established on shifting sand dunes in Co. Sligo, in about 1840 and although "not of much value as timber", was reported as being of "great benefit" forty years later (Kinahan and McHenry 1882).

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The stabilisation of coastal dunes

Afforestation of coastal dunes has been employed as a means of stabilising mobile dunes for several centuries. The first attempts at stabilising the shifting sands of Aquitaine were undertaken in Bayonne, in the sixteenth century. Planting of dune vegetation was followed by afforestation with "sea pines", presumably maritime pine (*Pinus pinaster* Aiton). In 1737, stone or umbrella pine (*Pinus pinea* L.) was planted to stabilise sand dunes in Doňana in southwest Spain (van der Meulen and Salman 1996).

The coastal dunes of Aquitaine stretch for 230 km from the Gironde estuary to the mouth of the River Adour, close to Bayonne (Figure 1). Since the Middle Ages, mobile dunes had made it almost impossible to inhabit the coast of Aquitaine as the sand frequently invaded villages (Cotton 1875), forcing their evacuation or relocation. The total area of the dunes is 124,000 hectares, 82,000 ha of which are classed as modern wooded dunes (Favennec 1998). Maritime pine makes up the vast proportion of these forests. In contrast to most of the artificial dune forests elsewhere in Europe, maritime pine is native to the area. This is the greatest area of coastal forest in Europe. Inland from the dunes, the great sandy plains of the moors of Gascony (*Les Landes de Gascoigne*) were almost equally inhospitable. These marshy, infertile plains were thinly inhabited by shepherds, who lived frugally off the land.

In the late eighteenth century, the early afforestation efforts in Bayonne were renewed with experiments conducted in the vicinity of Arcachon, close to Cap Ferret. Although interrupted by the Revolution, these trials were successful and the stabilisation of the dunes by afforestation then became a national initiative.

In the 1820s, it became clear that these coastal plantations were themselves being threatened by the continuous advance of the dunes and by the salt spray. At this time, fore-dunes (the area directly behind the beach) did not exist as strong onshore winds removed more sand than could be trapped by the vegetation (Paskoff 2001). An

Figure 1: *Map of France and Iberian peninsula.*

Figure 2: *Artificial dune in Aquitaine, France.*

artificial dune, a palisade of planks augmented by wattles and bundles of brushwood, was constructed over most of the length of the coastline. The primary purpose of this was to protect the forest. The surface of the dune was planted with marram grass (*Ammophilia arenarea*) and covered in branches taken from the forest to reduce the movement of the sand. Pine, in mixture with broom (*Cytisus* spp.) was established by direct seeding. Cotton (1875) gives a highly detailed account of the procedure. This technique proved very successful. By 1862, the entire coastline was protected by these dunes. The fact that essentially the same techniques are currently in use is testament to the innovation and ingenuity of those who developed them 200 years ago (Figure 2).

The artificial dune requires regular attention. It was well maintained until the beginning of the twentieth century (Barrère 1992), but subsequently underwent long

Figure 3: *Dune forest in Aquitaine, France.*

Figure 4: *Production forest in Leiria, Portugal.*

periods of neglect. It was damaged by storms and suffered severely during the Second World War, when the coastline was a restricted military area.

Although blowouts and incidents of invasion still occur, the coastal sands have now been stabilised and the whole region is now forested (almost entirely with maritime pine). The dune forests are located on the inland dunes (Figure 3). The non-wooded coastal dunes are still mobile, under the influence of the wind and the sea, which are constantly remodelling the coastline. The main threats to the dunes now are rapid marine erosion, intense aeolian dynamics and tourist pressure (Paskoff 2001).

The afforestation of the coastal dunes of Aquitaine coincided with a much larger project, *Reboisement* – the reforestation of France. As part of this, the great inland forest of *Les Landes de Gascogne* was established. This was quite separate from the coastal afforestation, although it was facilitated both by the stabilisation of the coastal dunes and the experience gained in their afforestation.

The work on the stabilisation of the dunes of Aquitaine subsequently inspired a similar approach in several other countries including the United Kingdom (MacDonald 1954), Denmark (Skarregaard 1989) and New Zealand (Gadgil and Ede 1998). Dune protection in the National Forest of Leiria (*Mata Nacional de Leiria*) in Central Portugal (Martins 1989), modelled directly on French practice, commenced in 1900. The forest is 11,000 ha in extent. It is composed of almost entirely of maritime pine, and although the great proportion of the area is managed as a production forest (Figure 4), it is truly multifunctional. There is a distinct protection area, with an artificial dune, and inland of it, a shrub zone of *Acacia horrida, Ulex* spp., *Erica* spp., *Corema album* and *Myrica faya* (Figure 5). Resin is still produced, although on a very small scale. The forest is heavily used for recreation; beekeeping, mushroom picking and hunting are also practised.

Figure 5: *Shrub zone, Leiria, Portugal.*

Dune afforestation in Ireland

There are a number of dune forests in Ireland, notably in Donegal (Murvagh, Ards Forest Park and Horn Head) and in Wexford (Raven Nature Reserve). Perhaps the best known is the Raven, at Curracloe, in Wexford (Figure 6). The land in this property is owned by the National Parks and Wildlife Service, but the forest stands are in Coillte ownership (Kilbride Forest). The property (217 ha) was acquired by the State in 1931 and afforested with a range of species including maritime pine, Scots pine (*Pinus sylvestris* L.), radiata pine (*P. radiata* D. Don) and alder (*Alnus glutinosa* L.). Deasy (1946), who described the establishment procedures and early performance in detail, refers to the "afforestation of wasteland". While there is little doubt that knowledge of the French experience gave a measure of confidence that the venture could succeed and also influenced the selection of species, notably maritime pine, it is clear that the primary management objective was not coastal protection. Indeed, despite the history of shifting sands, improved dune management and conservation have greatly reduced the problem and although recreational pressures have caused significant damage in some areas, large scale dune movement has not been a serious issue in recent decades. Given its current popularity for recreation, it is interesting to note that Deasy believed that the forest enhanced the landscape, stating that "the plantation already has an aesthetic value" contributing to the "improvement of the amenities of this stretch of coast".

Coillte have recently prepared a management plan (2011-2015) for Kilbride Forest (Coillte Forest 2011). The Raven is designated as a conservation area. According to the plan, 15 ha per year will be clearfelled and replanted, but to date, no felling has taken place as discussions on the future management of the reserve are ongoing between Coillte and the National Parks and Wildlife Service.

Figure 6: *The Raven, Co. Wexford.*

The future of coastal forests

The coastal forests of Aquitaine have protected the whole of the Landes de Gascognes for almost 200 years (Bartet 1997). However, the attitude to coastal dunes in general and to dune forests, in particular, has changed radically over the past 30 years. Awareness has grown that dunes are geomorphologically active environments and that the plants and animals which inhabit the dunes have evolved strategies to cope with the stress and disturbance brought about by the shifting sands, violent winds and salt deposition (Godfrey and Godfrey 1974). Concern for the conservation of the dune ecosystem has grown and with it the realisation that, rather than stabilising the dunes, their mobility should be promoted (Wanders 1989). Mobile dunes, if allowed to take on their natural forms of least wind resistance, will stabilise at a certain distance from the coastline. Where human settlements are threatened and stabilisation is necessary, the challenge is to achieve it without detracting from biodiversity and landscape values (Houston 2005). The ONF (Office National des Forêts), who manage much of the coast of Aquitaine, have been innovative in their approach to the management of coastal dunes. They have responsibility for the management of both the beach and the dunes and treat both as a single management unit. Dune mobility is promoted wherever it is reasonable to do so. Felling coupes are small, natural regeneration is encouraged and where this is not feasible, direct seeding is used. The wealth of habitats and species in inner dunes requires protection from mobile dunes on the ocean side and from anthropogenic influences on the land side. The coniferous forest provides and environment that favours the growth of native broadleaved species, such as pedunculate oak (*Quercus robur* L.), cork oak (*Q. suber* L.), olm oak (*Q. ilex* L.) and the strawberry tree (*Arbutus unedo* L.). The management objective is to move slowly towards a mixed pine-oak forest, so these species are promoted.

Management strategies have also been developed for the protection of other plant species, in particular very rare orchids (summer lady's tresses, *Spiranthes aestivalis* and the fen orchid, *Liparis loeselii*). The recreational pressures on the vulnerable dune ecosystems require careful management. Access to the beach is limited to managed footpaths, stabilised where necessary by wooden walkways. The public are made aware of the fragile nature of the dunes, by means of an educational programme including posters designed to inform without insisting on compliance.

Stands of maritime pine have had a long history of multiple use. The changing management objectives of the Forest of Lège, at Cap Ferret, Aquitaine, illustrates this (S. Métayer, ONF, pers. comm.). Originally, the forest was seen as having two functions, dune stabilisation and resin production. It was only in the 1930s that wood production was considered a management objective. By the 1950s, it had become the major objective. Commercial resin production ceased in 1974. In 1975, the forest was opened to the public with the construction of the first car park. Hunting also became important around this time. Recreation is the primary function and biodiversity is considered an additional function of the forest. The emphasis on production increases on a coast-inland gradient. Close to the coast, ecological, protection and recreational functions predominate.

The success of plantations in stabilising mobile dunes led to the indiscriminate planting of dunes whether or not they needed to be stabilised (van der Meulen and Salman 1996). Sometimes dunes were afforested purely for economic reasons with little or no consideration of a protective function. Geelin (2001) maintains that in the past there was an excessive concern for stopping blowouts and stabilising moving dunes. Some ecologists have called for the removal of dune forests, maintaining that the pine plantations eliminate most of the indigenous flora and fauna, as lowering of the water-table results in the loss of rare plants and the development of scrub. It is important that this momentum is tempered by a clear view of the objectives of such removals and a realistic assessment of the feasibility of achieving them. It is also important that the recreational and amenity functions that these forests perform today be recognised. Public opinion might prove to be a much bigger obstacle to large-scale clearance of dune forests, which have become very popular for recreation. Enlightened forest management might well prove a more realistic and effective solution. Rather than clearfell extensive areas of dune forest, it may be preferable to favour broadleaves, preferably native species, gradually converting pine monoculture to mixed forest (Houston 1989) to increase ecological diversity.

The Council of Europe has published a code of conduct for coastal zones (Council of Europe 1999). They point to the economic importance of coastal forests for tourism and recreation. While the environmental benefits of native forests are recognised, the negative impacts of intensive forest management, particularly with introduced species, are considerable. Nevertheless, while rehabilitation, including forest clearance is an option, the contribution of these long-established forests to biodiversity has to be acknowledged.

Conclusions

The practice of establishing forests on coastal dunes goes back almost 200 years.

Originally established with the single objective of stabilising shifting sands, they have become multifunctional in character. The goods and services which they provide could never have been envisaged at the time they were established. Sand stabilisation is often now unnecessary or may even be considered undesirable. Resin production has ceased or declined to insignificance. Recreation is now the major function of many of these forests. The ecological importance of the dunes is now recognised. The conservation of the dune ecosystems may necessitate the removal of forests in certain places but, whatever their origins, the forests established on the soft coasts of Atlantic Europe have become a permanent feature of the dune landscape, providing multiple benefits which are valued by society.

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Forest Perspectives

The story of Otto Reinhard: a case-study of divided loyalties, in peace and war

David O'Donoghue

One of the Irish State's most unusual civil servants, Otto Reinhard, ran the forestry service of the Department of Lands for four years in the 1930s. In mid-1939 he applied for Nazi party membership and, trapped in Germany at the outbreak of hostilities, remained there to support the war effort. Dr. David O'Donoghue looks back at Reinhard's career.

Foreword

This account of Otto Reinhard is to be welcomed; little is known about him in Irish forestry circles, other than the fact that he was Director of Forestry in the 1930s – even I got his initials wrong in my book[1].

Ireland is a country whose natural vegetation cover was forest, but from early times this was gradually eroded, by clearance for agriculture, by peatland growth, by commercial exploitation and finally by destruction under the influence of the Land Acts of the late nineteenth and early twentieth centuries. So that by the early twentieth century the area of forest in Ireland covered 1.2% of the total land area.

A Departmental Committee of 1907 recommended that "a comprehensive scheme of forestry…including the preservation and extension of existing woods, and the creation of a new forest area…be carried out by or under the direction of the State."

As a result, a Forestry Branch (!) was set up within the then Department of Agriculture and Technical Instruction for Ireland (DATI) which proceeded to acquire and plant lands, the first such being at Ballykelly, Co. Derry.

The forestry activities were taken over by the Forestry Commission after its establishment in 1919, but reverted to the Department of Agriculture following the Anglo-Irish Treaty of 1921. Forbes, described by MacLysaght[2] as, "an Englishman who is, by the way, devilish uninteresting outside the subject of forestry" and by Anderson[3] as "only half Scots", was first appointed as Forestry Advisor to the DATI, then under the Forestry Commission as Assistant Commissioner for Ireland and finally, in the new Irish Free State from 1922 as Director of Forestry. He retired in 1931 and was followed by John Crozier, a Scot, as acting Director, who retired in 1933. He was also described by MacLysaght as "a typical Scot of pawky humour and

[1] *Forestry in Ireland – A Concise History*. COFORD, 2004.
[2] *Changing Times*, Colin Smythe, 1978.
[3] *A History of Scottish Forestry*, Nelson, 1967.

very inelastic ideas on forestry". An international competition was set up to select his successor and the selection board to nominate him included Edward MacLysaght. In his account of the process he says that the candidate he preferred was "the only Irishman on the list: a genuine Irishman with an O name, hailing from Co. Limerick." But MacLysaght was in a minority of one. The man was not named but MacLysaght subsequently refers to him as "Mr. O'F". It has not since been possible to identify him. In the end, the final selection was Reinhard. I note that David O'Donaghue reports that the board was "unanimous" in selecting him. Reinhard was followed by another Scot; Mark Anderson, the then Chief Inspector was appointed. When he retired to take up a university post at Oxford he was succeeded, according to MacLysaght, "by another Scot", J.A.K. Meldrum, (sometimes known, I understand, as Jayky Meldrum) who was in fact an Englishman born in Carlyle, England and described also by MacLysaght as "an able after-dinner speaker who potters along awaiting his Civil Service pension". It is also notable that no Irishman was ever appointed to the post of Director which was discontinued after Meldrum's retirement in about 1953/4.

If an Irish forester had written this he would probably refer to the fact that Reinhard invited Prof. Walter Wittich, soil scientist, to visit and report on the Old Red Sandstone soils in Ballyhoura where afforestation attempts had proved unsatisfactory. Wittich's report was published (in translation) in *Irish Forestry*, Vol.6, p 29[4]. It offered no simple solution.

Reinhard was cautious about new departures. Tom Clear told me that when he was under political pressure to plant the western blanket bogs he went to one bog, possibly Cloosh, plunged his soil stick to the hilt and said, simply "*Es geht nicht*" (it's not on!)

I remember seeing another old file (on Ballyhoura) where Anderson was proposing various treatments but Reinhard wrote, in his thick black handwriting as described by David, "We should do no more work in Ballyhoura; it is wasting money". One can almost hear the v-sound in "work" and "wasting". The next item was a copy of a letter to the Forester-in-Charge, instructing him to lay off men.

Tom Clear is quoted by Joyce in my Concise History[4] as follows: "Anderson was a good silviculturist but something of an autocrat. According to Clear he resented Reinhard…and was always looking for ways to undermine him, such as the time when Reinhard wished to give foresters a uniform (similar to foresters on the continent) as a means of improving their lot without increasing their salary. Anderson immediately started a whispering campaign that Reinhard was bent on creating a movement similar to the "Brownshirts" or "Blackshirts" and that killed the idea."

There were probably more of Reinhard's observations in a series known as "technical files" dealing with correspondence with and reports on individual forests, but so far as I know, they were lost or have otherwise disappeared.

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4 Scherer, K. 1949. German forestry today. *Irish Forestry* 6: 29-37. Available at http://www.societyofirishforesters.ie/pdf/Journals/1949_VOL6_NO1&2.pdf

Otto Reinhard (1898-1947) is something of an enigma in the history of the Irish civil service – a German forestry expert who fought off 69 other candidates for the top job as director of forestry in the Department of Lands in 1935. He seems to have benefited from an unwritten and unofficial government policy – which was applied as much by the Cumann na nGaedheal administration as by its Fianna Fáil successor – of hiring experts of any nationality as long as they weren't English. This was perhaps understandable given the legacy of the bitter Anglo-Irish war of 1919 to 1921 and the new state's desire to distance itself from the former dominant power in London, not to mention extricating itself from the tentacles of the British civil service network. In that context, Reinhard was well placed to benefit from the new Dublin broom wishing to sweep clean and start afresh.

He certainly did not lack the necessary expertise, having studied forestry in Austria, France, Hungary, South Africa and Switzerland. A family memoir describes how, in 1924, Otto married Gertrud Steinvorth, the daughter of a wealthy Hanover businessman. Sometime later he was to be seen racing his convertible Mercedes through the streets of Kassel to attend forestry school "with his two Dachshunds barking on the back seat".[5]

Born on 14th January 1898 in Bad Wildungen, Waldeck, central Germany, Reinhard was the son of a high ranking civil servant, Gustav Reinhard. He had only one sibling, his sister Elisabeth. Like so many others of his generation, Otto Reinhard was destined for military service in the First World War, serving as a lieutenant from 1915 to 1918. He was awarded the Iron Cross, first class.

In the 1920s, Reinhard studied forestry at Hann-Münden forestry college and at university in Münster and Munich. He passed the Prussian state forest service's examinations in 1922 (probationer) and 1924 (assessor). After graduating, he was engaged as an assistant to Professor Hilf at Eberswalde forestry college, and was responsible for the college's forest range at Biesenthal. In October 1926, Reinhard became manager of the Naumburg forest range. In January 1928, he was appointed director of the Spangenberg forestry school (70 students per annum), as well as the local forest range. In April 1931, Reinhard was appointed conservator of the government forest range at Kassel. In the latter role he was responsible for the management of 88,000 acres covering 70 forests.

In 1933, Reinhard spent six months studying colonial forest management in South Africa's Transvaal, Natal and Cape provinces. In addition, he completed study tours in Austria, Hungary, Switzerland and France.[6]

Reinhard first saw Ireland from the deck of the German cruise ship SS Stuttgart which arrived in Galway from Hamburg on 7th July 1935. He took the train to Dublin for his job interview at the Department of Lands at 24 Upper Merrion Street, staying in the Royal Hibernian Hotel, Dawson Street. His personnel file reveals that he managed

[5] "Otto Reinhard und seine Familie" (Otto Reinhard and his family), 2004 memoir by Reinhard's granddaughter Marion Welsch.

[6] Undated profile of Otto Reinhard and Reinhard's own curriculum vitae dated 29th January 1935, both in his personnel file. Unless otherwise stated, all references to Otto Reinhard in this paper are from his Irish Department of Agriculture personnel file no. E1421.

to beat off no fewer than 69 other candidates for the job from America, Canada, New Zealand, Great Britain and "most other European countries", including Norway. A short-list of four candidates were interviewed in July 1935. Although not named on the file, the other three were Scottish, Irish and Norwegian. According to the file, the interview board was "unanimous" in selecting Otto Reinhard.[7]

On 15th August 1935, the German was offered the "temporary, non-pensionable post" of director of forestry for one year and accepted it two weeks later, on 1st September. It carried an annual salary of £1,300 in addition to tax-free travelling expenses of £250 based on 10,000 miles a year at 6d per mile. (This total income of £1,550 would be equivalent to €115,509 in 2012 values, according to the Central Statistics Office.)

The Reinhard family (Otto, his wife Gertrud – they had married in 1924 – and their two children, Rolf and Elisabeth, aged nine and ten, respectively) arrived to start their new life in Ireland, landing at Cobh on 16th November 1935. The German had brought his own car with him and drove the 160 miles with his family to Dublin. Two days later, Reinhard reported for duty at the Department of Lands. The family stayed temporarily in the Royal Hibernian Hotel before renting a furnished house "St. Helen's" in Sandycove, south Co. Dublin.

As director of forestry, Reinhard had a countrywide workforce of approximately 2,000 (according to reports of the Minister for Lands on forestry, for the period he was in charge). He was based not in the Department of Lands headquarters, but just around the corner at 88 Merrion Square which housed the Forestry Division.

In 1938, in keeping with his improving status (his salary rose to £1,500 per annum in May 1938 or €123,550 in 2012 values when travel expenses are added), Reinhard purchased a splendid Victorian mansion in its own grounds, "Rossmore" on Silchester Road, Glenageary, Co. Dublin. A contemporary photograph (Figure 1) shows the director of forestry entertaining members of the German show-jumping team in his extensive gardens, which included a private tennis court. The team were competing at the RDS horse show that August.

No sooner had Reinhard taken up his new post in Dublin, than the newspapers reported the new arrival. Under the heading "German Forestry Expert" the *Irish Press* of 19th November 1935 pictured a coy looking German, clutching a felt hat with one hand, the other nonchalantly in his trouser pocket. A smart suit was topped off with a white handkerchief peeping out of a breast pocket. The photo caption read: "Herr Rheinhardt [sic] – the new director of afforestation for the Irish Free State, photographed in Dublin yesterday." The following day, *The Irish Times* reported

[7] Edward MacLysaght, who was a member of the interview board (along with its chairman J.J. MacElligott, Robert Barton and Michael Deegan, Secretary of the Department of Lands) paints a somewhat different picture of the unanimity involved. In his 1978 memoirs, Changing Times (pp. 223-4), MacLysaght notes that his first choice for Director of Forestry was the Irish candidate but adds that: "I was in a minority of one." He then opted for Reinhard, explaining: "Barton agreed with me in this; the others were undecided. As normally happens in a committee, when two or three members have decided views and the rest have not, the former carry the day. The result was that Reinhardt [sic] was appointed. He was in fact only a moderate success and when the war broke out in 1939, he returned to Germany …". MacLysaght was mistaken in thinking that Reinhard returned to Germany "when the war broke out". As this paper shows elsewhere, the German was on holidays in Germany when war was declared, and this prevented his return to Dublin.

Figure 1: *Otto Reinhard (third from left, at rear) pictured in the garden of his home "Rossmore", Silchester Road, Glenageary, Co. Dublin, in summer 1938 with members of the German show-jumping team that competed at the RDS Horse Show that August.*

Reinhard's arrival under the heading: "Afforestation in Free State; German expert in Dublin to direct all operations; big problems to be tackled." The paper described Reinhard as "a typical German, about six feet tall, in the late thirties and he speaks very good English". Reinhard told *The Irish Times*' reporter that "he was greatly interested in his new post. He had already made himself acquainted to some extent with the problem he had to meet, with the history of Irish forests, and with the fact that in recent times the country had been almost completely denuded of trees." Reinhard also told the reporter it was "his intention at the outset to visit every part of the country, study the soil and other conditions, and in a few months' time he hopes to present to the Department of Lands a report on the situation, with recommendations as to the type of trees suited to the various localities. Much would, of course, depend on the amount of money that the Government was prepared to spend".

But not everyone was as prepared as de Valera's *Irish Press*, or *The Irish Times,* to give Reinhard an easy ride in his new job! First off the mark was the Labour Party leader, William Norton, who tabled a Dáil question on 28th November 1935 – a mere ten days after Reinhard had taken up his new post – asking "whether a non-national has been appointed to the important position of Director of Forestry" and "if applications for this position were received from nationals of the Saorstát. Norton pressed Seán O'Grady, the parliamentary secretary to the Minister for Lands, to "indicate the considerations that caused the giving of the appointment to a non-national". Replying, O'Grady confirmed that "applications for the post were received from Saorstát nationals. Having regard to the considerable expansion proposed in the work of the Forestry Division and the consequent importance of the post, it was necessary to secure the services of an officer having the highest qualifications in forestry science, together with experience of administration." O'Grady defused Norton's attack by adding: "The candidate who was appointed has excellent technical qualifications and has had considerable practical experience of forestry operations on a large scale and of forestry administration. He has also an extensive knowledge of the timber trade and has studied forestry conditions in a number of countries." But this still wasn't enough to satisfy all tastes because Deputy John Good asked "if the person appointed has a speaking knowledge of Irish".[8]

There is no evidence that the Labour leader returned to the fray following that comprehensive reply. But, two months later, Reinhard again came under the microscope from the New York-based *Irish Echo* newspaper. The *Echo* was anti-de Valera and linked to Joe McGarrity's Clan na Gael movement (which advocated closer IRA links to Nazi Germany and, from 1938, a military campaign in England). In a strongly worded editorial entitled "An appointment that rankles", in its edition of 25th January 1936, the paper railed that: "A number of Irishmen, employed in various State and federal forestry departments in this country [i.e. the United States], are raising Cain over a recent appointment made in the Irish Free State." The Irish Echo went on to name Reinhard (misspelling his name Rheinhardt, as it had appeared in the Irish Press two months earlier), describing him as having held a "minor post as tree surgeon" in New York. The paper then named various Irish foresters working in New York who it claimed were "equally well qualified and … would have been glad of an opportunity to get a job at home – but not one of them heard of the vacancy". The Irish Echo criticised the Dublin authorities for not having advertised the post in America, adding that if certain specialists cannot be found in Ireland, the Irish government should seek them "among the Irish abroad". In a final attack on Reinhard's appointment, the paper said "the Irish Free State government should have exhausted the possibility of securing a qualified Irishman before giving the job to a man of a different race".[9]

While it may not have had an audience at home, the *Irish Echo*'s barbed criticism stung officials in Dublin. In response, the Minister for Lands (under whose aegis the forestry section came) Senator Joseph Connolly, took steps to put the record straight in the US papers. Connolly was no doubt sensitive to US opinion on Irish affairs, given that he had acted as consul-general for the Irish Republic to the United States from 1921 to 1922 (i.e. prior to the Treaty split). Connolly instructed de Valera's ambassador in Washington, Robert Brennan, to issue a statement to the US papers making it clear that the vacancy for forestry director had been advertised in two US publications, *Journal of Forestr*y and *American Forests*. The statement added that "applications were received from a large number of competent men resident in various countries, including the U.S."

Connolly's riposte took the *Irish Echo* to task for getting Reinhard's name wrong – the paper had named him as Augustus Rheinhardt, while his correct name was Otto August Feilius Reinhard – and mistakenly reporting that the German had worked for the New York Parks Department. "The Director of Forestry, Herr Otto Reinhard, was not at any time engaged in forestry work in the United States", Minister Connolly's note thundered, adding that "the candidate who was appointed has excellent technical qualifications and has had considerable practicable experience of forestry operations on a large scale and of forestry administration. He has also an extensive knowledge of

8 Official Report, Dáil Éireann parliamentary debates, 28th November 1935, volume 59, col. 1549, question no. 2742.
9 The Irish Echo, "An appointment that rankles", 25th January 1936.

the timber trade and was regarded by the [interview] board as being the best qualified of all the applicants".

In the event, Connolly's rejoinder went unnoticed by the *Irish Echo* newspaper, which failed to publish it. But in its edition of 1st February 1936 the *Irish Echo* did print a short letter from Robert Brennan pointing out that Reinhard's job had been advertised in two American forestry journals and that "there were several American applicants for the post". Meanwhile, the *Irish Voice* in Boston, reproduced Connolly's statement in full.

Large sections of Reinhard's personnel file for the years 1935 to 1939 are taken up with his pay and conditions. It is clear from the exchanges that the German wanted a salary of £1,500 – roughly equivalent to that of Dr Eduard Hempel, the German ambassador in Dublin – rather than £1,300 per annum. Although initially engaged on a temporary, annual renewable contract in November 1935, by 1937 Reinhard was being offered establishment, i.e. a permanent pensionable job in the Irish civil service. The catch was, however, that this would have reduced his income to £1,000 a year. The German had no intention of taking such a pay cut, even if it meant he would have a permanent job plus a pension at 65 years of age. Later on, Reinhard would have reason to regret this decision as it made it much easier for his employers to terminate his employment when war broke out in September 1939. It also meant he had no recourse to regaining his old job after the war.

Although effective and apparently contented in his job, Reinhard maintained contact with Germany, particularly as he was technically on leave of absence from his work with the German state forestry service. In 1937, Reinhard informed his employers in Dublin that he was thinking of returning to his pensionable job in Germany. This prompted a flurry of memos between various Departments on Merrion Street. On 14th

Figure 2: *Pictured at Avondale in 1937, (left to right) Otto Reinhard, his daughter Elisabeth, Alistair Grant (junior Inspector at Avondale) and A.C. Forbes (ex-director at Avondale).*

October 1937, the secretary of the Department of Lands Michael Deegan, drafted a private memorandum for the Minister for Lands, Gerry Boland (who had taken over that portfolio in November 1936). Deegan was clearly worried about losing Reinhard: "I am most strongly in favour of retaining Mr. Reinhard here. He has the qualities necessary in a successful head of the Department and should he leave us I do not know where we could turn for a successor. The next in command, Dr. Anderson, chief inspector, though an excellent official in his own special line, has quite definitely not got the qualities called for in the technical head of the Department, and he too may soon be gone from us as he is a candidate for the professorship of forestry in the Aberdeen University, and he is not unlikely to be appointed."

Deegan ended the note with a plea to Gerry Boland: "It would be a most serious matter for us to lose Mr. Reinhard now that he has made himself acquainted with us and with our conditions and that we are able to benefit fully by his experience and ability." In a hand-written note in the margin, the following day, Boland tells Deegan: "I raised this matter with the Minister for Finance [Seán MacEntee] to-day and have asked him to treat it as urgent."

But MacEntee had a tight grip on the State's purse-strings and was unwilling to grant Reinhard any special conditions. In a letter to his cabinet colleague Gerry Boland, dated 28th October 1937, the Minister for Finance pointed out that if the German director of forestry accepted an annual salary of £1,000 plus bonus and pension (he was then earning £1,300 with no pension entitlement), he would be getting more than comparable posts in other State agencies.

MacEntee told Boland: "I am aware that Herr Reinhard is regarded as almost ideally suitable for the directorship of forestry. It is only because I am conscious of these things that I would be willing to agree to a salary of £1,000 a year [i.e. as part of a permanent, pensionable contract] … a higher figure would, in my opinion, be impossible to justify". MacEntee's parting shot made it clear that he did not share the view of the Department of Lands that Reinhard was indispensable: "I shall be surprised if he decides to go, but if he does I am afraid we must make the best of it. We can hardly be expected to compete with the German government for the services of one of its own citizens, or to grant to a German terms that we would not dream of offering to an Irishman."

So the Minister for Finance dug in his heels and in the ensuing months Reinhard played something of a cat and mouse game with his Irish employers, explaining all the extra benefits he would enjoy in Germany. This is clear from yet another lobbying letter from Boland to MacEntee, dated 6th December 1937: "Mr. Reinhard does not wish to leave us; he would, in fact, like to stay here where he has a job that appeals to him – building up something that he can see growing and flourishing under his own hand and about which he has ideas which he would wish to try out. But he has explained to Mr. Deegan that he is exceptionally well placed in his home department [in Germany]… he is given the services of a chauffeur; has certain rights of sporting over a wide area; has a longer holiday allowance than with us and in addition can have odd days [off] at his own discretion."

Otto Reinhard was in a difficult position, however, as in late 1937 he was summoned to Berlin to discuss taking a new job there. The German forestry service was targeting him as the head of a new international section. According to Michael Deegan, Reinhard thought "that the possibility of the return of some of Germany's African colonies may have something to do with the need for the new section being opened in his department to handle international business".[10]

After just over two years' work as director of forestry, Reinhard dropped his bombshell on 3rd January 1938, penning a letter of resignation to Deegan: "I regret I have to resign my position as director of forestry with effect from the end of February 1938." The letter caused consternation in the Department of Lands, but the German had effectively left his employers with no option but to accept that he was leaving for Germany. On 12th January 1938, the Government Information Bureau issued a press release announcing that Reinhard "is being recalled to Germany by his department [i.e. the German forestry department] to undertake new duties of an important nature in Berlin and will sever his connection with Irish Forestry at the end of February. The Minister for Lands has conveyed to Herr Reinhard his regret and that of the Government at the loss of services, which have already, even in the short period of two years, proved of very great value, and has also conveyed to Herr Reinhard the Government's high appreciation of the manner in which his services have been discharged". The next day the Irish Press carried the story under the headline "Recalled to Berlin – Forestry Director leaving next month". In addition to repeating the Government Information Bureau's statement, the newspaper reported a recent visit by Otto Reinhard to Leitrim and Mayo to investigate reafforestation schemes.

Meanwhile, moves were afoot behind the scenes to try to tempt Reinhard to stay in Ireland. Gerry Boland appears to have given up lobbying the Minister for Finance for a pay rise for the German, and instead writes directly to the Taoiseach, Eamon de Valera, who was then in London (accompanied by Seán MacEntee) for the Anglo-Irish conference, which would see Britain relinquishing control later that year of the Treaty Ports at Lough Swilly, Castletownbere and Cobh.

In his letter of 22nd February 1938 to de Valera, which begins "Dear Chief", Boland reveals that "I was at dinner recently with the German Minister [i.e. Hitler's ambassador to Dublin, Dr. Hempel]. Herr Reinhard was also present. In the course of the conversation, I expressed regret that we were losing our forestry director, and the Minister [Hempel] said that perhaps he could get the German Forestry Department not to insist on Herr Reinhard's recall for the present". Boland told Dev he understood "that there is still a chance of retaining Herr Reinhard's services. I am very anxious to retain him but I cannot ask him to stay unless I can offer him the salary acceptable to him. He will remain with us for a further period of three years on a temporary basis for a salary of £1,500 per annum, we to pay cost of removal of his furniture from Germany and grant him 42 days annual leave. He has 30 days leave at present and £1,300 per annum".

Boland then effectively asks Dev to overrule MacEntee: "As you are keenly interested in our forestry operations, I would ask you to talk the matter over with the Minister for Finance if you think it desirable. I regret very much troubling you while

[10] The "international business" referred to was Berlin's plan to import additional timber supplies from sources beyond Europe – presumably as part of its general rearmament programme.

you are so busy but the time is short as Herr Reinhard must complete his arrangements for sailing on 9th [March]."

Despite the pressures on him in London, de Valera must have approved the deal as, a week later, a flurry of correspondence between the Department of Lands and the Department of Finance results in a fresh three-year contract for Reinhard at £1,500 a year, plus extra leave. Whether or not Reinhard was playing the Irish off against the Germans, he got what he wanted, which was a higher income. The lucrative salary would enable him to move to a much bigger house, "Rossmore" on Silchester Road, in the leafy Dublin suburb of Glenageary from where he would enjoy a busy social life.

But in the meantime, Reinhard had sailed back to Germany where he would spend March and April preparing for his return to Dublin. Acting as if he were still in charge at 88 Merrion Square, he instructed departmental officials "that he wants to see no disturbance or movement or recruitment till he comes back – so far as the inspectors are concerned".[11]

In fact, Reinhard was based in Hanover from where he kept in regular written contact with Michael Deegan. The letters, in the German's clear, bold hand-writing style, survive in his personnel file in the Department of Agriculture in Dublin. In one such letter, dated 12th March 1938, Reinhard tells Deegan that he cannot finalise his plans to return to Dublin until he meets with the head of the German forestry service who was on holidays in Italy until the end of March. Reinhard is upbeat about the Irish forest service's plans for 1938: "We should certainly overstep the 9,000 acres [planting] figure if the weather is so favourable as it is over here." He then adds a mini-bulletin of political news from Germany: "We found everything all right in Germany and the German people are just enjoying the end of that unfortunate partition: Austria/Germany. I sincerely hope you will also succeed some day with the abolition of a troublesome border!" Reinhard presumably thought he was telling Deegan what the Irishman wanted to hear. In any case, the German must have been caught up in the hype following the Anschluss or annexation of Austria by German troops on the same day he wrote the letter.

On 5th April 1938, Reinhard was able to tell Deegan that he could accept the offer to return to Dublin as director of forestry, adding that "my family and I feel all very happy to come back to Ireland… I am looking forward to take over again a job and a task I always liked so much". On 26th April, Reinhard informed Deegan that he would resume duties on Monday, 16th May. As usual, Reinhard ends his letter with a little political sweetener for Deegan: "The German press is full of the latest Irish news: the President [i.e. de Valera] and the Anglo-Irish agreement."

A press statement by the Government Information Bureau on 27th May 1938, revealed that Herr Otto Reinhard "has returned to Dublin to re-occupy the post of Director of Forestry for an additional three years". But despite the seemingly harmonious relations between the Irish civil service and its peripatetic director of forestry, Reinhard would only remain in Ireland until August 1939. This was because he was stranded in Germany following the outbreak of war, having left Dublin in mid-

[11] Nally to Deegan, 1st March 1938.

August to spend the holidays in Kassel.

In the late 1930s, however, Reinhard was, to all intents and purposes, a pillar of the small German community, an occasional dinner guest of German ambassador Dr. Hempel, as well as attending meetings of the German colony in Kilmacurra Park Hotel, Co. Wicklow, which was run by a Sudeten[12] German called Karel (aka Charles) Budina. According to a February 1945 profile by the Irish Army's military intelligence section, G2, Reinhard "was a frequenter of that hotel where Nazi meetings are known to have been held".[13]

In his 1938 letters from Germany to his boss, Michael Deegan, there is nothing to suggest that Reinhard opposed what was happening in his native land, including the annexation of Austria. It is unclear what prompted him to apply for membership of the NSDAP or Nazi party in mid-1939, but his links to Dr. Adolf Mahr (head of the local party branch or Ortsgruppe) may provide a clue. Mahr – an Austrian Nazi who was director of the National Museum – regularly recruited Germans and Austrians resident in Ireland to the party ranks, even using coercion and bully-boy tactics on occasion. No sooner had Reinhard arrived in Dublin in 1935, than Mahr arranged to give him a tour of the National Museum. In any case, Germans were expected, even required, to report directly to Dr. Mahr when they came to Ireland.[14]

According to one study, there were no fewer than 32 Nazi party members in Ireland in the 1930s (not counting German exchange students who were obliged to join the NSDAP to get permission and funding to travel). Six of these party members were on the Irish state payroll working in various branches of the public service.[15]

The Irish Army's profile of Reinhard describes the German as "a typical military man in appearance; is very charming and is something of a 'gay dog'. He is, nevertheless, an able individual and was efficient in the discharge of his official duties. He is believed to have known this country very well indeed and to have had a particularly thorough knowledge of the eastern seaboard. He was a friend and associate of Karl Petersen of the German Legation. He was also on intimate terms with the Budina brothers of Kilmacurra Park Hotel …".[16]

Whatever led Reinhard to join the Nazi party, he appears to have made up his mind to do so in or around June 1939. His party membership card is dated 1st September 1939, but the average delay in granting membership after an application was approximately two months. A family memoir, written by Reinhard's granddaughter some 60 years after the war, indicates that he applied to join the party in June 1939. According to Adolf Mahr's daughter, Hilde Strassburger, Mahr asked Reinhard to be his successor as local Nazi party boss, but Reinhard refused. (Thus his decision to join the NSDAP at that time may have been a compromise to avoid taking over Mahr's

[12] Sudentenland was the German name, used in English, referring to the northern, southwest and western regions of Czechoslovakia and derived from the Sudetes Mountains bordering Silesia and Poland.

[13] G2 report, dated February 1945.

[14] O'Donoghue, Hitler's Irish Voices, p. 20. See also, Gerry Mullins's 2007 biography of Dr. Adolf Mahr entitled Dublin Nazi No.1: The Life of Adolf Mahr. NSDAP stands for Nationalsozialistische Deutsche Arbeiterpartei (National Socialist German Workers' Party, commonly abbreviated to Nazi party).

[15] O'Donoghue, *op. cit*., pp. 219-20.

[16] G2 report, February 1945.

leadership role.) In the end, that job went to Heinz Mecking, the chief advisor at the Turf Development Board.[17]

In mid-1939, Mahr had come under pressure to choose between his Nazi party activities and his role as director of the National Museum, and chose to quit as party boss. Similarly, in 1934, his predecessor, Colonel Fritz Brase (director of the Irish Army's school of music since 1923) was forced to choose between his army career and his role as NSDAP chief in Dublin. Brase quit his Nazi job and stayed with the Irish Army, but apparently remained a rank and file Nazi party member.[18]

There is nothing to suggest that Otto Reinhard planned to spend the war years in Germany. A Department of Lands' document shows that in July 1939, for example, he spent ten days carrying out forestry inspections in places as far apart as Portarlington (Co. Laois), Ashford and Cong (Co. Mayo), Tuam (Co. Galway), Kinnitty (Co. Offaly), Dundrum (Co. Tipperary), Emo (Co. Laois) and Co. Wicklow forests at Glenmore [sic], Glencree, Roundwood, Glenealy, Avondale and Aughrim.[19]

On 18th August 1939, he left Dublin with his wife Gertrud, planning to take 27 days' annual leave in Kassel. He notified his employers of the forwarding address at 11, Königstrasse. He would normally have been back at his desk at 88, Merrion Square in mid-September. But like some other members of the German colony, including Mahr, Reinhard found himself stranded in Germany when war broke out at the beginning of September.

When Reinhard failed to return to Dublin on Monday 18th September, his absence sparked a flurry of internal memos in the Department of Lands. And it is clear from this correspondence that opinions were divided on whether or not to sack him. The German had a strong advocate in Michael Deegan, the top official in the Department of Lands, who was on good personal terms with him. But the tide appears to have swung against Reinhard not least because his erstwhile supporter Gerry Boland (who had lobbied de Valera a year earlier to keep him in Dublin by offering a higher salary) had left the Department of Lands on 8th September 1939 to become Minister for Justice. Boland's successor was Tom Derrig whose correspondence shows no sympathy for the German at all. So it seems as if that change of ministerial portfolios may, in fact, have scuppered whatever chance Reinhard had of retaining his post in absentia and resuming it after the war.

It is worth noting that Adolf Mahr – who, unlike Reinhard, was a permanent and pensionable member of the Irish civil service – was unable to resume his job as National Museum director after the war. The Dublin authorities moved swiftly to pension him off. The only Nazi party member on the pre-war Irish state payroll who was allowed to resume his job after the war – as professor of sculpture at the College of Art in Dublin – was Friedrich Herkner.

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17 Welsch, *op. cit.*

18 O'Donoghue, *op. cit.*, pp. 19 and 23.

19 In a handwritten note dated 17th August 1939, Reinhard listed his inspections from 5th to 31st July, including one at Glenmore, Co. Wicklow. The Glenmore Castle estate, near the Devil's Glen, comprised 786 acres a century ago. It was formerly owned by the family of John Millington Synge and is now run by Coillte under the name Glanmore. (The author is grateful to Dr. Michael Carey, forestry consultant, for this background data on Glenmore Castle.)

On 19th September 1939, the day after Reinhard was due back in Dublin, Deegan's assistant, Mr. W.F. Nally penned a strongly-worded memorandum for the new Minister, Tom Derrig, pointing out that the German "has not returned and since it is known that he is on the strength of the German Army of Reserve and is a man of suitable age for active service [he was then 41] it is virtually certain that he is occupied on military duties and will not be available at least during the period of the war". Nally added that "by failing to resume duty on the cessation of his annual leave without any notice or explanation Mr. Reinhard has, in fact, terminated the employment himself and I think that we would be safe in regarding our contract with him as being broken by his own act". Nally then suggests that the chief inspector of the forestry section, Dr. Anderson, should be asked "to discharge the duties of director in a temporary capacity". Nally's memo pointedly notes that Anderson's "salary of only £641 per annum" was less than half Reinhard's income of £1,500.

It is hard to avoid the conclusion that Nally's memo is a pre-emptive strike to oust Reinhard from his top job and install Dr. Anderson in his place, taking advantage of a newly arrived Minister to achieve this goal. Perhaps Dr. Anderson had been the Irish candidate short-listed for the director's post in 1935. Whatever the internal politics of the Department of Lands, however, Michael Deegan now found himself in agreement with Nally to appoint Dr. Anderson as acting director of forestry. In a hand-written note in the margin of Nally's memo to the Minister, however, Deegan says "We must wait for a week or two to see if we hear anything from Mr. Reinhard". Three days later, on 22nd September 1939, Nally issued a written instruction that "payment of salary should be withheld from Mr. O. Reinhard, Director of Forestry".

The first that officials in Dublin heard of Reinhard was a letter, dated 9th October 1939, from the German's solicitor Arthur Cox stating that it would be Reinhard's "hope and intention to return as soon as circumstances may permit". The German had contacted Cox through the Irish legation in Berlin, asking the Dublin solicitor to act on his behalf. Cox wrote to "The Secretary, Forestry Department, Government Buildings, Dublin" as follows: "As you are aware, the position is that Dr. Reinhard went to Germany on his usual holidays, shortly before the war commenced, and owing to the war it has not been possible for him to return to this country."

On 14th October 1939, Frederick Boland of the Department of External Affairs, informed Deegan that Otto Reinhard had recently visited the Irish *chargé d'affaires* in Berlin, William Warnock, asking "whether it would be possible for the Irish Government to arrange for his return to Ireland through Great Britain, that being the only route now available. In the present circumstances, the Minister for External Affairs [i.e. de Valera, who was also Taoiseach] cannot see his way to approach the British Government for a safe conduct to enable Dr. Reinhard to return to this country through England". By contrast, de Valera had only a short time earlier arranged for members of the German colony to return to Germany via Holyhead and London in a special deal for the "enemy aliens". They sailed from Dún Laoghaire aboard the mailboat on Monday, 11th September 1939 – i.e. eight days after the outbreak of war.[20]

[20] *ibid*. pp. 29-32. Strictly speaking, Great Britain was not "the only route now available" to return to Ireland because an air link (using flying boats) operated between Lisbon and Foynes.

On 20th October 1939, Michael Deegan wrote to the new Minister for Lands pointing out that Otto Reinhard was one month overdue at work. The tone of the letter clearly shows that Deegan has turned against the German and no longer supports him. He tells Tom Derrig: "I feel strongly that he has not treated us as we were entitled to expect that an officer holding his position would treat us. To leave here on the 18th August for a month's holiday in Germany could hardly be described as a prudent act – certainly not for a well-informed person who wanted to return to his business without fail. Even so, there was plenty of opportunity to return in the concluding days of August; thousands of people who were in Germany on holidays returned home or crossed the frontier to other countries. If Mr. Reinhard were a free agent and wished to get back to his work here, he could have done so also. It was his duty to have so arranged his affairs as to be able to resume with us at the end of his holiday … Is there anything gained by keeping his name as director on the books, for that is what it amounts to? I cannot see that there is, nor can I see that he has any claim on us. I therefore agree with Mr. Nally that his appointment should be terminated – and that he has in fact terminated it himself by his failure to return to duty."

On 25th October 1939, Tom Derrig replied to Deegan stating that "Herr Reinhard's appointment should be terminated", and adds that the Attorney General should be consulted "as to the legal position". An internal letter from Deegan to the Department of Finance, dated 31st October 1939, reveals that the Attorney General (Patrick Lynch) "holds that by failing to resume duty on the expiration of the leave granted to him, Herr Reinhard has, in fact, himself terminated his employment and broken his contract".

On 5th November 1939, Otto Reinhard writes to William Warnock at the Irish legation in Berlin, but he is clearly unaware of the moves to sack him in Dublin. He says: "I have the greatest confidence in "good old Ireland" which we all liked so much – if I may say so to you – that everything will be all right again. We spent happy years over there and I only hope I can take up duty again. I hope I did some useful work in developing forestry in Ireland. I'm sure the huge forests with standing timber we bought during my stay under difficulties – will be a great asset to the country just now. The organisation built up will certainly be able to meet all requirements to overcome a scarcity of timber." Reinhard then signs off with the words, "I did not give up hope that I shall see Ireland again in better times".

A report of a meeting on 18th November 1939 between representatives of the Departments of Finance, Lands and External Affairs revealed only one dissenting voice in favour of Otto Reinhard. According to the report, Seán Moynihan, secretary of the Department of Finance "put it to us very strongly as his view that the termination of Mr. Reinhard's contract might be regarded as unwarranted since it seemed to him that it was through no fault of Mr. Reinhard that he did not return to his duty when his leave period was over". But a contrary view came from Frederick Boland, assistant secretary of External Affairs, who said it was "very fortunate that Mr. Reinhard had, himself, stayed out of the country as a very awkward situation would arise if he were now, as a German national, in occupation of an administrative post in our Civil Service. The Department of External Affairs would not like to feel that Mr. Reinhard might succeed in getting back to this country during the period of the war; and if he were here, consideration might have to be given to his position".[21]

The decision to dispense with his services was formally conveyed by letter to Otto Reinhard on 30th November 1939 – via his solicitor Arthur Cox and through the Irish legation in Berlin. W.F. Nally of the Department of Lands told Reinhard: "It appears that in present circumstances there is no hope that you would find it possible to return to this country. You will, of course, understand that the annual leave commencing on the 18th August 1939 granted to you by the Department was granted on the understanding that you would resume duty in due course. Since you have failed to return to duty, the contract under which you were appointed by the Minister to the temporary post of Director of Forestry has been determined by you."[22]

Then, in a classic "good cop/bad cop" ploy, Michael Deegan also wrote to Reinhard on the same date, saying: "We have had, of necessity, to consider your position in the Service and the official decision which has been addressed to you is, in the nature of things, as regrettable as it is inevitable. Since your valuable services are no longer available we must, of course, make other arrangements to supply the directional needs of the Forestry Division … I regret that circumstances over which we have no control should have brought our happy relationship to a close." In a separate letter to Arthur Cox, the Department of Finance issued a cheque of £148 for Reinhard to cover back pay and holiday pay.

Otto Reinhard finally got around to replying to the official letter of dismissal by personally calling to see William Warnock at the Irish legation in Berlin on 9th January 1940. According to Warnock's report, Reinhard 'said that he regretted that the Department of Lands had not seen its way to keep his position open. He had, of course, broken his contract technically, but he could hardly be held responsible in present circumstances. He felt that the Department's action was hardly in the spirit of the contract, and that their official letter to him could have been couched in more friendly terms. On the other hand, he appreciated the personal letter from Mr. Deegan". Warnock ended his report with the following comment: "On the whole, Dr. Reinhard does not appear to suffer from any bitterness. He seems to be more disappointed than anything else."[23]

But if the head of the Department of Lands, Michael Deegan, had any fear or trepidation about his ex-director of forestry arriving unexpectedly back in Dublin during the war, any such notions were well and truly dispelled when, on 7th March 1940, he received a letter out of the blue from Reinhard, postmarked Bucharest (Romania was occupied by Germany from 1941 to 1944). In his missive, the German reveals that "As I could not return to my post [i.e. in Dublin, after the outbreak of war] – being called up as Captain in the army – I decided to accept the job in Roumania when it was offered to me. It is very interesting but difficult in every respect. This is

[21] For whatever reason, Boland failed to mention that other Germans occupied state jobs in late 1939. They included Dr. Adolf Mahr (on leave of absence from the National Museum) and Friedrich Weckler (chief accountant of the ESB).

[22] In fact, the words "by you" were added by Nally after consulting the Attorney General's office, presumably to make it harder for Reinhard to appeal his dismissal, if he chose to do so. In a memorandum of 20th November 1939, Nally wrote: "I have consulted Mr. Phillip O'Donoghue, Attorney General's Office in regard to the drafts. He agrees with them provided we insert the words *'by him'* in order to make it clear that Mr. Reinhard has himself determined the contract of employment."

[23] Boland to Nally, 30th January 1940.

a great country for a forester and the huge Carpathian Mountains are wonderful. I just returned from an inspection on ski as there is still heavy snow in the mountains. I am director general of an exploitation firm renting concessions from State, Church and private owners, developing the forests and not only simply cutting – as other firms did over here – leaving a "mess" when they left the forest. That's the reason why they wanted a forester on top and not a Jewish timber merchant!"[24]

Reinhard's letter also deals with the termination of his contract as director of forestry in Dublin: "I have received the official letter via the Irish Minister [i.e. Warnock in Berlin] but I was a bit disappointed that all connections with Ireland are cut off now. I fully understand the position and I was very glad to have your private lines attached to the official bulletin. Thank you so much. Otherwise there would have been the impression that you were only too glad to get rid of your temporary forestry director. In fact, some people were under the impression!"

Reinhard goes on to explain to Deegan that while he is in Romania, his family are at home in Hanover, and his furniture is in Ireland. Perhaps making a pitch to regain his Dublin job later on, the German adds: "I made it clear that this is only a temporary job, that I will be free to decide later what to do after the war." And from the snow-capped Carpathian mountains, Reinhard still finds time to refer to Irish forestry conditions, telling Deegan: "I was glad to hear that you are well and that you are busy planting at least some 6,000 acres. It is good that you have plants in the nurseries and I'm sure Dr. Anderson and the whole staff will keep things in good order. There is now a certain tradition in your forestry service, and it will be possible to overcome difficulties with the staff you have. All good wishes for the future… kind regards to Mr. Nally."

In penning this letter, Reinhard was of course unaware of the steps both Nally and Deegan had taken to ensure that the German's three-year contract (which was supposed to run until May 1941) was terminated early. Nonetheless – despite Reinhard's anti-Semitic comment and his clear disappointment that the director's job was not being kept open for him – the only part of Reinhard's letter that seems to have concerned Deegan was the following short paragraph, which he marked with an "x": "I would be very glad if you could give me some sort of certificate that I was in your service from November 1935 until August 1939 and that I have some qualities. [In fact, Reinhard's appointment was terminated from 5th September 1939, despite the fact that he was not due back from leave until 18th September]. One does not know how and when the war is going to end and if it might not be necessary to start again to build up a new existence." On the same day he received the letter from Bucharest, Deegan sent a copy to his deputy W.F. Nally with a handwritten note in the margin: "Mr. Nally, What do you say about "x"?"

Deegan took a cautious approach towards drafting a reply to his former employee and did not issue a response for almost a month. In the eventual letter, dated 2nd April 1940, he tells Reinhard: "We are all glad to know that you are pleased with your new surroundings and that you are employed again on forestry work, which I am sure you

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[24] Reinhard's letter was written eight months before Romania joined the Axis powers (on 23rd November 1940) led by "a coalition government of radical right-wing military officers under General Ion Antonescu". From 1941 to 1944 "at least 270,000 Romanian Jews were killed …" (source: United States Holocaust Memorial Museum, Washington D.C.).

will enjoy more than many another war-time job. Dr. Anderson is now in the post of director and is doing quite well in that capacity. There is no other important change since you left. All the time the good work that you did for us while you were here is bearing fruit and when you come back to see us I hope you will not be disappointed."

Deegan then attached a reference that the German had sought: "Herr Otto Reinhard was appointed to the post of Director of Forestry in the Department of Lands on the 18th November 1935 … he occupied that post until the 4th September 1939. For some weeks previous to that date Herr Reinhard was absent on leave in Germany. On the outbreak of war he intimated that he would be unable to resume his duties in Ireland in due course and his employment was therefore terminated. Herr Reinhard's services as Director of Forestry were of great value to this Department, and his efficiency, conduct and performance of duty were in every respect most satisfactory."

While couched in polite terms, Deegan's letter and reference appear deliberately designed to leave Reinhard under no illusion as to the impossibility of resuming his old job. The letter is somewhat misleading in stating that Reinhard occupied the post of director "until the 4th September 1939" (the German had taken a month's leave from 18th August and was not due back until 18th September). In addition, Deegan's reference, though glowing in some respects, is also disingenuous in stating that Reinhard "intimated that he would be unable to resume his duties in Ireland". In fact, the German had written to the Irish *chargé d'affaires* in Berlin (on 5th November 1939), stating: "I only hope I can take up duty again."

Deegan then inexplicably sent the letter and reference to Bucharest in the ordinary post, but given the wartime postal restrictions it was unlikely to reach Reinhard. Deegan appears to have realised his mistake six weeks later when in mid-May, he sought the help of the Department of External Affairs to send the correspondence to Berlin via the diplomatic bag. To be doubly sure that Reinhard got the letter and reference, Deegan also sent copies to the German ambassador in Dublin, Dr. Hempel. There is no record of any subsequent response from Reinhard to his former employers in Dublin.

Little is known about Otto Reinhard's activities in the war years, apart from the fact that he continued his forestry work in Romania until late March 1942. In 1941, he bought his father Gustav's house in Bad Hersfeld. In 1944, his son Rolf joined the army, while his daughter Elisabeth joined the labour service or Arbeitsdienst. In 1942, Otto Reinhard was drafted into the war effort as an army captain, but was exempted from active service on foot of a doctor's certificate diagnosing high blood pressure and heart problems. From 1942 to 1945, he worked first for the Reich forestry service, travelling between Berlin and Landershausen, and later for a company making wood-fuelled gas-generators.

In July 1945, Otto Reinhard was interned by the American forces in civilian internment camp 91 at Darmstadt. His good knowledge of English meant he quickly became "camp master". He was freed after nine months captivity, in April 1946.

In his de-nazification files, Reinhard is described as a "Mitläufer" – i.e. a "fellow traveller" but not actively involved in any atrocities. Despite surviving the war, Reinhard had little more than a year left to live. He died in February 1947, aged 49, from a kidney infection which could not be cured due to the lack of proper medical treatment in occupied Germany in the immediate post-war years. His condition was hampered by continuing blood pressure and heart problems. A family memoir notes that Otto Reinhard's death notice coincided with the receipt of a letter offering him a top job as head of the Berlin region's forestry service. His wife Gertrud survived him by 26 years, dying in 1973 aged 71.[25]

In February 1945, five months before Reinhard was interned by the Americans, Irish military intelligence, G2, produced a background note on the German giving brief details of what was known about him. The report noted that in 1941, three German women were residing in Reinhard's Dublin house "Rossmore" on Silchester Road, Glenageary. They were two typists from the German legation at 58, Northumberland Road, Dublin – Else Lacamp and Trude Friedinger. The third woman, Heimlinde Dittrich, was a radiologist at St. Vincent's Hospital. Reinhard's granddaughter, Marion Welsch, notes that the three women kept "everything in order" and "the place aired". When Otto Reinhard's widow, Gertrud, went back to "Rossmore" in 1948, "she finds the house in good condition. Only Otto's tuxedo and a few Persian carpets are moth-eaten!"[26]

The G2 report contains a handwritten addendum based on an interview with Abwehr (German military intelligence) agent Helmut Clissmann (who ran the German academic exchange bureau in Dublin in the 1930s) in Rome in March 1943, according to which "Reinhard was directing the German radio programmes to Ireland". In fact, from 1941 to 1945, the programmes were run by Dr. Adolf Mahr (on leave of absence from his job as director of the National Museum, Dublin) and Dr. Hans Hartmann a German linguist who had studied Irish at UCD in the 1937-39 period. The handwritten note adds a caveat that the man referred to by Clissmann "might not be Reinhard, but J[upp] Hoven, who is believed to have used this name [i.e. Reinhard] sometimes". Despite G2's suggestions, there is no evidence that Otto Reinhard had any connections with German radio programmes targeting neutral Ireland during the war.[27]

On 4th May 1946, the head of G2, Colonel Dan Bryan, wrote to Frederick Boland at the Department of External Affairs, with a brief report on Dr. Adolf Mahr and Otto Reinhard. Col. Bryan wrote that information of a serious nature had come to hand "to the effect that Mahr approached one of the German intelligence sections, which dealt with matters concerning a landing in Ireland, with a long report and was, as a result, employed in that section for a year or two. Consequently, he is now detained in Germany and still more information may be forthcoming. Also employed in this section with Mahr was Dr. Otto Reinhard of our forestry department. This is the first time we heard of Reinhard since 1939. This information should, in my opinion, make the Departments concerned be still more hesitant about any proposal to re-employ these people in the immediate future".[28]

Dan Bryan's source was the British intelligence service MI5 with whom he had

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25 Welsch, *op. cit*.
26 *ibid*.
27 G2/0245, Otto Reinhard. See also D. O'Donoghue, *Hitler's Irish Voices* for the history of Germany's wartime radio propaganda services to neutral Ireland, 1939-1945.
28 Bryan to Boland, 4th May 1946, G2/0130 Mahr.

close contacts. Mahr was in a British military internment camp in Germany from January to April 1946, and was released on grounds of ill health. Reinhard was also released from detention in April 1946, although he had been in a different camp. The Mahr and Reinhard files contain no further elucidation on their alleged roles in a German intelligence section "which dealt with matters concerning a landing in Ireland".[29]

The May 1946 G2 report may simply have been a case of mistaken identity, particularly in the case of Reinhard who appears to have been involved primarily in forestry work during the war. Colonel Bryan told Boland that his information was "not yet complete". It is extraordinary that Bryan did not check Reinhard's whereabouts with the Department of Lands who could have told him of the German's forestry work in Romania. In addition, Bryan seemed unaware that, while Mahr was on leave of absence from the National Museum, Reinhard's contract had been terminated on 5th September 1939, almost seven years earlier – a fact that could easily have been verified with his former employers. It appears that Otto Reinhard remained an enigma for the Irish authorities long after he had left Dublin.

Conclusion

At its height, the Austro-German community in Ireland numbered 529 in 1936. It had dropped to 460 by 1946, principally due to its members who chose to leave Ireland for Germany in the late summer of 1939. Otto Reinhard was part of that colony, but was also a member of a much smaller number of 32 Germans and Austrians who joined the Nazi party's Ortsgruppe or local branch in Ireland. In addition, Reinhard (who joined the Nazi party on 1st September 1939) was one of only six NSDAP members who were also Irish state employees. The others were (date of joining Nazi party): Colonel Fritz Brase, director of the Irish Army school of music (1st April 1932); Friedrich Herkner, professor of sculpture, College of Art (1st September 1939); Dr. Adolf Mahr, director, National Museum (1st April 1933); Heinz Mecking, chief advisor, Turf Development Board (1st June 1931); and Friedrich Weckler, chief accountant and later company secretary, ESB (1st June 1934).

The aforementioned six people were attempting a difficult if not impossible balancing act – earning their livelihoods from the Irish state, while swearing loyalty to the Third Reich. Colonel Fritz Brase was the first head of the Nazi party branch in Dublin. But under pressure from the army chief of staff, Major-General Michael J. Brennan, to choose between the Irish Army and the Nazi party, Brase opted to relinquish his NSDAP leadership role, which was taken over by Adolf Mahr in 1934 (the same year he was promoted to be director of the National Museum). Five years later, Mahr in turn came under pressure due to his less than covert activities on behalf of the German national socialists. He gave up his post as party chief in mid-1939

[29] G2 and MI5 may have been confused by the fact that one of Mahr's employees at the German Radio service – Tralee-born John O'Reilly – was parachuted into Co. Clare on 16th December 1943. But the parachute drop had nothing to do with either Mahr or Reinhard. It was the work of the SS-run *Sicherheitdienst* or SD, the Nazi party's security and intelligence service. The SD dropped a second agent (John Kenny) in the same spot three days later. Both men were arrested and imprisoned. See O'Donoghue, op. cit., pp. 212-3; and O'Halpin, *Defending Ireland*, p. 241.

and was succeeded by Heinz Mecking. It is noteworthy that Otto Reinhard declined Mahr's offer to succeed him as local NSDAP leader.

As the Second World War drew nearer, the position of these Nazis became increasingly untenable, and this was particularly so for those on the Irish state payroll. Some, including Reinhard, were stranded in Germany when war broke out. Others opted to avail of safe passage – negotiated by de Valera with London – through Britain on 11th September 1939, eight days after the declaration of war. Some may have returned to Ireland if that had been an option but when the chips were down they did not refuse to aid Hitler's war effort.

In the case of Otto Reinhard (Figure 3), a study of his voluminous dossier in the Department of Agriculture archives in Dublin confirms his positive contribution to the Irish forestry service in the 1935 to 1939 period. His qualifications, professional attributes and central role in the development of the forestry sector are not in question. What remains a mystery, however, is how someone like Reinhard – and many of his NSDAP colleagues – could turn their backs on a country that had provided them with top jobs, an enviable standard of living, good prospects, and security for them and their families. The alternative – which they might have worked out, had they stopped to think about it – was to risk losing all in a conflict provoked by a fascist tyrant who had turned Germany into a police state. Members of the German colony in Ireland can hardly have been in any doubt about the direction Germany had taken since Hitler became chancellor on 30th January 1933. So why did they favour Hitler's Germany over their host country? Was it a case of dangerously divided loyalties, misguided feelings of obligation and/or duty, duress by Adolf Mahr, or a somewhat naive belief that the war would quickly be won by Germany and they could thus resume their former lives in Dublin? It may have been a combination of some or all of these factors. But those who opted to join the Nazi party had, in doing so, sworn allegiance to the Third Reich and may therefore have felt beholden to the Führer above all else. Others may simply have wanted to help their country in time of war.

Figure 3: *Otto Reinhard pictured in October 1936, a year after becoming Director of Forestry at the Department of Lands (photo courtesy of Irish Military Archives).*

As regards the six Nazi party members in the Irish public service, four of them spent the war years in Germany. The two who remained in Dublin were Fritz Brase who died at home in Sandymount in December 1940, aged 65, and Friedrich Weckler who died at home in Dalkey in 1943, aged 51. Heinz Mecking went to Russia with the German army in 1941 to work on turf production for the winter campaigns there. He died as a prisoner of the Red Army in Tiraspol, Soviet Moldova, on 18th December 1945. As we have seen, Otto Reinhard died of health complications following a kidney infection in February 1947, aged 49. Adolf Mahr tried and failed to get his Dublin museum job back; he died of a heart attack in Bonn in May 1951, aged 64. Professor Friedrich Herkner was the only one to make it back to Ireland. He resumed teaching at the College of Art in Dublin, where he remained until his retirement in the 1960s.

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Note on author

Dr. David O'Donoghue is an author and historian. In addition to *Hitler's Irish Voices,* he has written two other history books. They are *The Irish Army in the Congo 1960-1964: The Far Battalions* (Dublin, 2005); and *The Devil's Deal: The IRA, Nazi Germany and the Double Life of Jim O'Donovan* (Dublin, 2010).

Appendix

A record of planting and felling in the Irish state for the period during which Otto Reinhard worked in Ireland follows in Tables 1 and 2, respectively.

Table 1: *Forestry plantation programme, 1930-1940 (ha).*

Year	State	Private	Total
1930	1,250	100	1,350
1931	1,270	100	1,370
1932	1,250	100	1,350
1933	1,700	100	1,800
1934	2,250	0	2,250
1935	2,800	150	2,950
1936	3,000	100	3,100
1937	3,000	150	3,150
1938	3,050	100	3,150
1939	2,725	100	2,825
1940	*2,400*	250	2,650

Source: Department of Agriculture, Dublin.

Table 2: *Forest felling programme, 1933-1943 (acres).*

Period	Area felled
1930 - 1934	*782*
1934 - 1935	*741*
1935 - 1936	*587*
1936 - 1937	*498*
1937 - 1938	*498*
1938 - 1939	*736*
1939 - 1940	*565*
1940 - 1941	*829*
1941 - 1942	*924*
1942 - 1943	*938*

Source: Reports of the Minister for Lands on Forestry.

Addendum:

Notes on Otto Reinhard, the forester

Michael McNamara, a native of Cratloe, Co. Clare began his career in forestry when he entered Avondale Forestry School in 1935. He would serve as a forester in a number of locations including Cahir, Ravensdale, Cong, Freshford and Jenkinstown. He was acquisition inspector covering the southern part of the country when he retired in 1976. A former two-term president of the Society of Irish Foresters, he went on to play a prominent role in private forestry after his retirement.

Michael McNamara met Otto Reinhard during his time as a student and briefly after he qualified. He describes him as a "good talker" and an excellent lecturer. "Alistair Grant, a Scottish forester provided the weekly lectures and we were fortunate to have two excellent visiting lecturers in ML Anderson and Otto Reinhard," he recalls (McNamara, 2011-12).

Anderson lectured every month while Reinhard's talks were less frequent. The two differed in their approach according to McNamara. "Anderson was clear and decisive but could be prickly and authoritarian in his relationship with students," he said. "He was a born lecturer but the advice was 'not to question him,'" The youthful Clare student failed to heed on one occasion. "I got on well with him until one day when he was discussing windblow, I offered an alternative view to his, he recalls. "My comment was given in the spirit of youthful enthusiasm, but Anderson took exception to my remark, which he perceived as questioning his knowledge and his authority. It was neither, but he barely acknowledged me after this."

He says that lectures by Reinhard were more relaxed. "He was a tall man and was at ease in the classroom – laid back and sure of himself would be the best way to describe him. Unlike Anderson who didn't encourage questions, Reinhard accepted question and debate. He went out of his way to explain his viewpoint." McNamara says that Anderson placed strong emphasis on commercial forestry and issues such as good thinning practice. "Reinhard put great emphasis on German silviculture and as far as I can recall, he also discussed a wide subject area including amenity forestry. He had plans for an urban forest in the Dublin Mountains."

After his spat with Anderson, Michael was relieved when Anderson (then acting director of forestry in Ireland) was replaced by Reinhard as director when his final exams and interviews came around in 1938. Along with another student – Joe Deasy – he was chosen for work experience in Wageningen, Germany in 1939. They had scarcely arrived when they were ordered to return home, just before the outbreak of World War II.

His plans to develop the forests around the Massey and the Hell Fire Club as an urban forest may have given the impression that he veered towards recreational rather than commercial forestry. Neeson (1991) provides a contrary view:

"Reinhardt[30] well understood that the purpose and functions of a modern

[30] The misspelling of Reinhard's surname has been a common mistake in much of the Irish literature as has already been mentioned by OCarroll and O'Donoghue.

> forest was to supply timber to the market-place profitably. While there was no comparison with the steps being taken in England, under Reinhardt the sale and marketing of timber in Ireland was taken seriously for the first time."

According to Jack Durand (1969), Reinhard "does not appear to have left a particular stamp of German forestry on forestry thinking [in Ireland]".

His views on public use of the forest were far in advance of thought in Ireland at the time. An area in the Dublin Mountains was being planted at the time and his views on species to be employed were conditioned more by future usage of the area, rather than the accepted species blocks for timber production. As German forests were open to the public, Reinhard believed in the opening to walkers of Irish forests and at Killakee, Co. Dublin, he provided for canoeing and picnicking by leaving selected areas unplanted. In keeping with such developments however, he wished as in Germany that foresters should have statutory authority, with police functions and he discussed the desirability of foresters wearing uniforms, to allow easy recognition.

According to McNamara, Reinhard really enjoyed his stay in Ireland and didn't want to leave. He recalls meeting him briefly in 1939 in Merrion Square before he left for Germany: "Although the outbreak of war was a few months away, he recognised that it was inevitable. He gazed at some flags in the distance from the steps of the Department of Lands offices and said 'I have no choice but to return to Germany as there is no place to hide'. My distinct impression at the time was that he did not wish to return."

Donal Magner

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Two Simple Site Classification Systems

Niall OCarroll

Various systems of site classification are in use in forestry. A selection of these are cited in Farrelly et al (2009) and elsewhere. Many of those proposed systems are of a complicated nature involving complex functions of a number of site characteristics. Indeed, Farrelly desiderates "the development of practical models, using only variables that are easily available" which would be "more accessible to forestry practitioners". Two such simple "models" have been in general use in Ireland, although their derivations have not so far been formally published.

1. Pre-acquisition assessment

In the State Forest Service of the Republic of Ireland, pre-acquisition assessment of potential forest land and post-acquisition selection of species to be planted were largely influenced by a scheme proposed by Anderson (1950). (The scheme described by Farrelly (2012), used in British Columbia, a two-way classification by site moisture regime and indicator species, appears to be remarkably reminiscent of that of Anderson.) The Irish scheme proved rather successful in a context of state afforestation, but required skill and experience for disinterested or impartial application.

The pre-acquisition valuation procedure was based on costs of crop establishment and management and the value of future revenues. This followed an assessment of site factors including geology, soil, topography, and vegetation, leading to an estimate of potential yield class (Bradley et al. 1966, Hamilton and Christie 1971). From these data, a money value was derived as a basis for negotiation. The present writer carried out a study (unpublished) of twenty sites in which the pre-acquisition yield class estimate was compared with the forest inventory assessment of yield class twenty years later. The regression line of field-assessed yield class on pre-acquisition estimate indicated a close relationship and the means of the two estimates approximated to a fraction of a yield class unit. To estimate the proportion of variation in achieved yield class explained by the pre-planting estimate would require access to the raw data which, regrettably, are no longer available to me.

This exercise established that trained and experienced foresters could reliably forecast potential yield class on bare ground. Two anomalous cases occurred. One of these was clearly due to repeated frost damage and the other had no obvious explanation. A unique copy of the original report on this study was passed over to Coillte after that body was constituted[1] and neither it nor any other copy could subsequently be found, but the main details of the result remain firmly in memory (Joyce and OCarroll 2003).

[1] It is a matter of infinite regret to me that I failed to keep a copy of a report I prepared on this exercise before I passed it over to Coillte. Several enquiries within Coillte have failed to discover the report or any surviving copy.

This finding supports the view expressed by Worrell (1987) that "this [described] system is designed to augment the knowledge of practicing forest staff, not to replace it. In many cases estimates of productivity and planting limits made by locally experienced staff will be as good as, or better than, estimates using this [system]".

2. Assessment by map ornament

In recent years, from the 1960s onwards, the quality of land available for state afforestation was generally low and fertilizer use, principally phosphate but also in certain cases potassium, was necessary. Observation of existing crops and fertilizer experiments on Sitka spruce indicated that site fertility, reflected in fertilizer response to applied phosphate fertilizer were related to the map ornament used in the Ordnance Survey 1:10,560 (6-inch-to-one-mile) maps, Figure 1 (Ordnance Survey of Ireland, n.d.) and this relationship was then further investigated .

It was noted that the highest yields were associated with sites shown as "fields and ornamental ground" and this was designated "fertility class A". These were areas enclosed by walls, fences or ditches, had been under intensive agricultural use up to relatively recent times and still carried characteristically agricultural pasture vegetation. They generally equated to Anderson's (1950) grass-herb and grass-rush communities.

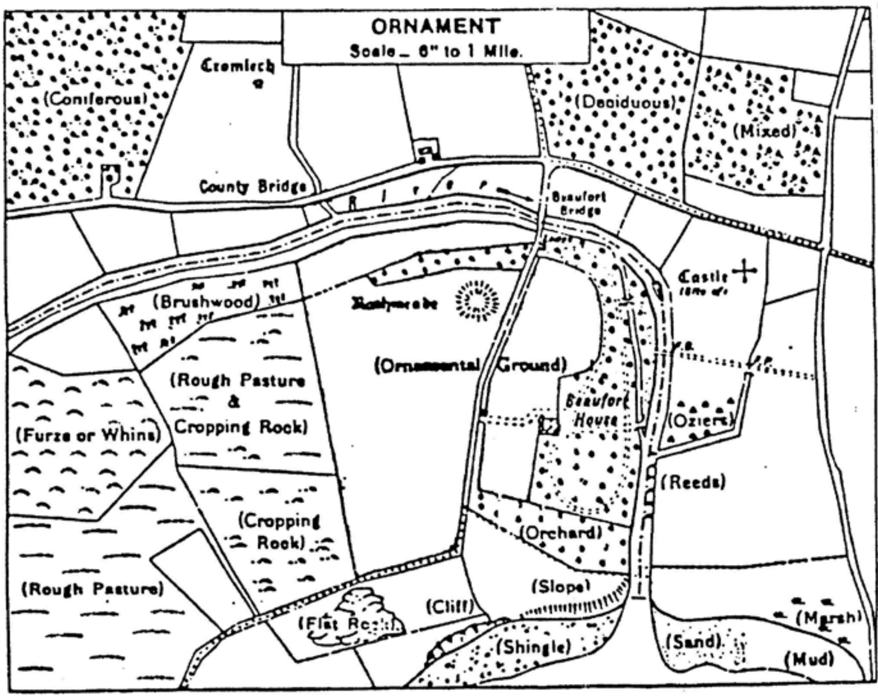

Figure1: *Ornament used on 6-inch-to-one-mile (1:10560) Ordnance maps. Ordnance Survey of Ireland (Copyright Permit MP 000212).*

The lowest yields were attained on sites shown as "rough pasture" with or without "cropping rock". This was designated "fertility class C". These areas were generally unenclosed in the sense that they had never been fenced in or brought under any agricultural use other than rough grazing, usually with sheep at low stocking rates. In a context of land use, they were "fenced out" rather than "fenced in". They frequently had a surface layer of deep peat. Mineral soils in this class are normally derived from quartzite or sandstone parent material.

Intermediate yields were found on sites usually enclosed and denoted "furze or whins"[2]. The fact of enclosure indicated that at one time they were considered sufficiently fertile to bring them into agricultural use and it is very likely that they were cultivated and manured. The presence of furze (*Ulex* spp.) further indicated that the land had not been intensively managed for a long time. Further, *Ulex* spp. have the capacity to fix and accumulate atmospheric nitrogen (O'Toole et al. 1974) and so would have contributed to later fertility. Such sites were retired from intensive agricultural use when a reduced land area was needed for agricultural production either as a result of decreasing levels of population or increasing production on better land due to improved technology.

A number of other sites were on land denoted as "woodland" (coniferous, deciduous or mixed). This gave no indication of inherent productivity, but merely reflected the land use preference of a previous owner or in some cases the semi-natural woodland cover which had never been cleared. These were designated class X. Occasionally these might be of good fertility, but never brought into cultivation because of steep slope (or rock outcrop).

Potassium fertilizers

Potassium deficiency and response was invariably confined to midland areas receiving average annual precipitation-contained potassium of about 2 kg/ha or less (OCaroll and McCarthy 1973) and then only on sites on man modified fen peat (Hammond 1979) and shown on the maps as fields (plain, no ornament).

It has also been shown that on a western oligotrophic peat soil with a 22-year-old crop of lodgepole pine (*Pinus contorta* Dougl.), the potassium content of trees and soil was 85 kg/ha greater than that of an adjacent unplanted site. It is postulated that this unexplained accumulation is accounted for by the potassium content of local precipitation (Carey and OCarroll 1981), thus implying that additional potassium may not be necessary on such sites and that the presence of a thriving tree crop, established with the aid of phosphate fertilizer, can further improve site fertility by capturing potassium from the rain.

These conclusions on map ornament and potassium were circulated within the Forest Service in 1975.

Assessment for grant-aid

However, where forestry is primarily commercially motivated and subsidized by state grants and where potential productivity may be estimated by the owner, by

[2] Whins is the English common name for *Ulex* spp. in the northern part of Ireland (Lucas 1960).

a consultant or by a contractor, a more objective approach is required. This also emerged from the site assessment based on map ornament described above, chiefly the "enclosed/unenclosed" element and the finding that better yields could generally be attained on classes A and B sites than on class C. This fact was used to discourage the planting of unenclosed land by offering a lower grant level or refusing pre-planting grant approval if the site was considered below the economic limit for planting.

Thus it proved possible to classify forest sites without having resort to difficult and expensive research projects, but with quite satisfactory practical outcomes.

Conclusion

These two systems of site classifications are presented here for what they are; they have proved useful in the practice of forest establishment and management in Ireland. But we (you!) must continue to try and devise systems that depend on totally objective and quantitative data rather than the indirect or subjective and experience-based methods described here.

Acknowledgement

Staff of the Forest Service Research Branch contributed to the study of assessed as compared with estimated yield class.

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Trees, Woods and Literature - 36

Many people recognize trees by their leaves or by their general shape and size, but walking through the leafless deep bush Roy knows them by their bark. Ironwood, that heavy and reliable firewood, has a shaggy brown bark on its stocky trunk, but its limbs are smooth at their tips and decidedly reddish. Cherry is the blackest tree in the bush, and its bark lies in picturesque scales. Most people would be surprised at how high cherry trees grow here—they are nothing like the cherry trees in fruit orchards. Apple trees are more like their orchard representatives—not very tall, bark not so definitely scaled or dark as the cherry's. Ash is a soldierly tree with a corduroy-ribbed trunk. The maple's grey bark has an irregular surface, the shadows creating black streaks, which meet sometimes in rough rectangles, sometimes not. There is a comfortable carelessness about that bark, suitable to the maple tree, which is homely and familiar and what most people think of when they think of a tree.

Beech trees and oaks are another matter— there is something notable and dramatic about them, though neither has as lovely a shape as the big elm trees that are now nearly all gone. Beech has the smooth grey bark, the elephant skin, which is usually chosen for the carving of initials. These carvings widen with the years and decades, from the slim knife groove to the blotches that make the letters at last illegible, wider than they are long.

Beech will grow a hundred feet high in the bush. In the open they spread out and are as wide as high, but in the bush they shoot up, the limbs at the top will take radical turns and can look like stag horns. But this arrogant-looking tree may have a weakness of twisted grain, which can be detected by ripples in the bark. That's a sign that it may break, or go down in a high wind. As for oak trees, they are not so common in this country, not so common as beech but always easy to spot. Just as maple trees always look like the common necessary tree in the backyard, so oak trees always look like trees in storybooks, as if, in all the stories that begin "Once upon a time in the woods," the woods were full of oak trees. Their dark, shiny elaborately indented leaves contribute to this look, but they seem just as legendary when the leaves are off and your can see so well the thick corky bark and its grey-black colour and intricate surface, and the devilish curling and curving of the branches.

These lines are taken from *Wood*, one of 10 stories featured in *Too Much Happiness* by Alice Munro (2010). Born on July 31st, 1931, Munro (nee Laidlaw), was brought up on the family farm close to Wingham, Ontario. Apart from a 21-year period during her marriage to Jim Munro when the couple lived in Vancouver, with their three children, she has lived in Wingham and nearby Clinton. She now lives in Clinton with her husband Gerald Fremlin.

Although she has travelled widely, much of her writing is based on her early experiences of the people, the places and countryside of southeast Ontario. Her ability to convincingly and vividly describe this rural landscape and its associated activities was influenced by her upbringing on the family farm. Her father was a fox farmer who sold fur to traders. In her 1968 story *Boys and Girls*, from *Dance of the Happy*

Shades (2000), she adopts the role as his helper when skinning the foxes: "I found it reassuringly seasonal, like the smell of oranges and pine needles."

In *Wood*, Roy, the central character is neglecting his work as an upholsterer to fell firewood in the local hardwood bush. Married to Lea, the elderly couple have entered a crisis period in their lives as Lea is obviously suffering from depression. As he walks the bush, he ponders their relationship and her illness: "[He] misses the wife he was used to, with her jokes and her energy."

He knows the trees intimately and the felling techniques required. However, he becomes agitated when he hears a rumour that his casual arrangement to purchase firewood may be at an end. The harvesting may be put out to contract and he knows he can't compete against the big companies, so he is in a hurry to fell as much timber as he can before this imagined event takes place. However in a mixture of anxiety, haste and overfamiliarity with his work, he becomes careless and is seriously injured.

Readers will be impressed by Munro's ability to switch from her vivid description of the woodland inscape to Roy's ensuing injury and his despairing, painful and slow crawl back to his truck. She is not a writer tempted by optimistic endings but *Wood* is an exception. There is hope at the end as Lea comes to her husband's rescue and only a writer of Munro's talent could give this conclusion such a convincing ring.

It is interesting to contrast Munro's description of the various landscapes she encounters. In some stories the intimate countryside of her youth is replaced by the large-scale terrain of distant landscapes with their contrasting topography and species. On a train journey from Ontario to Vancouver, Juliet the central character in *Chance* from *Runaway* (2005) looks out at a much different landscape from her carriage window: "The trees were mostly evergreens, pine or spruce or cedar. The spruce—black spruce—had what looked like little extra trees, miniatures of themselves, stuck right on top."

And when the narrative leaves this landscape of "Rocks, trees, water, snow", suddenly, almost as an afterthought, or chance, she reconnects with the forest: "*Taiga*, she thought. She did no know whether that was the right word for what she was looking at." Of course with Munro, nothing is left to chance. *Taiga* or the Boreal Forest is the exact word she is looking for; the cold and lonely biome that stretches beyond North America to Russia and Scandinavia.

Likewise, all the time Roy is in pain, he is trying to remember another name for the bush or woodland. All he knows is "It's a tall word that seems ominous but indifferent". And as his reinvigorated wife rescues him, he remembers: "*Forest*. That's the word. Not a strange word at all but one he possibly never used. A formality about it that he would usually back away from."

Readers who visit Canada or who attended the Society study tours in Ontario and British Columbia in recent years will be familiar with parts of the Munro landscape. While the trees she describes are different from Irish grown species and varieties, the bark descriptions have a familiar feel. The "corduroy-ribbed trunk" description of ash and the "elephant bark" of beech could be applied to a mature common ash and beech growing in Ireland. W.S. Graham (2004) also made a similar comparison with beech in *Imagine a Forest*: "Go on between/The elephant bark of those beeches/Into that lightening, almost glade."

Seamus Heaney (1983) takes up the soldierly qualities of ash in *Sweeney Astray:* "life-blood on a spear-shaft/darkens the grain of ash." Her remarks that beech bark is ideal for carving initials would have found favour with Lady Gregory when she selected a copper beech in Coole Park in the 1890s as the 'Autograph Tree'. It still stands with the initials of William Butler Yeats, Sean O'Casey, George Bernard Shaw and other writers and artists. The original "slim knife groove" carvings are still legible but becoming "wider than they are long".

As well as featuring trees and woodlands in her writings, Munro is a strong advocate of sustainable forestry development. She walks her local woodlands, which she wishes to see protected against expansion of corporate farms (Edemariam, 2003) and also supports the conservation of old growth forests.

She has received numerous awards including three of Canada's Governor's General Literary Awards, two Giller Prizes and the National Book Critics Circle Award. In 2009 she received the Man Booker International Prize for her overall contribution to fiction at a ceremony in Trinity College Dublin.

Donal Magner
Wicklow,
June, 2012.
Selection by
Gerhardt Gallagher

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Book Review

Wolves in Ireland
A natural and cultural history

Kieran Hickey. Open Air imprint of Four Courts Press. 2011.
Hardback. ISBN 978-1-84682-306-0.
€20.00

The author has produced an interesting history of the Irish wolf (*Canis lupus*). The book, a slim volume of 155 pages, gives a well-researched record of the rise and decline of the wolf in Ireland. The wolf was both feared and respected by the native Irish people. The howling of wolves has been described by someone as one of the most terrifying sounds in nature and by others as one of the most exhilarating. An individual wolf is a beautiful, strong and intelligent animal and when you consider that they hunt in packs of five to ten animals they become a dangerous efficient predator. In this country their prey was the Irish elk, the boar, and domestic animals and on occasions humans -in particular children. Yet individual animals were tamed and used for hunting, skins were a prized possession for warriors; teeth were used as good luck charms and various body parts for medical potions.

The wolf pre-dated the presence of humans in Ireland by around 20,000. The earliest confirmed date for the wolf in Ireland was that of a mandible or jawbone radiocarbon-dated to 27,500 ± 420 years BP. There is some difficulty in distinguishing wolf bones from dog bones but this problem only arises post-human colonization of the island. Traces of wolf, along with many other wild animals, have been found at many Mesolithic campsites from 9,000 years ago. Wolves, probably pups reared by humans, were used for hunting and many types of dogs have been bred from the wolf including the Irish wolf-dog or the later Irish wolf-hound. Ringforts were built partly as defense against wolves and to protect livestock. The bawns of castles were used to house livestock for protection against thieves and wolves, while the poor brought the animals into their cabins at night for safety.

A fascinating chapter deals with the heritage we have inherited in the form of wolf related names. The author has identified forty-six place names in eighteen counties with a wolf component based on the Irish names for wolf and thirteen in nine counties with English language "wolf" place names. Reference to wolves can be inferred from a number of ogham stones in Ireland. Irish personal names can be associated with wolves. Conall meaning "strong as a wolf" where as Ó'Faoláin has been translated as wolf. Personal research will be required to establish the meaning of the author's reference to the "evil connotations" associated with Ó'Faoláin.

The wolf is feared in terms of superstition, being a favourite disguise of the Devil and linked to evil even in children's stories. Wolves, because of their ferocity and aggression, were often associated with battle. Yet the wolf occupied a special place in the literature of the early Irish saints. Wolves were one of three wild mammals (fox and red deer the other two) considered as pets in the Brehon Laws. Wolf parts were used extensively in medicine to cure consumption, treat epilepsy and ailments of the eyes. The belief that some Irish could change into wolves and werewolves was often used as a political slur against the native Irish.

The Historic record of wolves in Ireland up to 1786 can be gleaned from a number of sources. Wolf incidents were recorded in the writings of the day especially by visiting monks. There was a series of regulations governing human interaction with wolves from the farming perspective, and a list of herdsman's duties with respect to wolves. Based on the customs books for ports in the UK, wolf skins were imported from Ireland. The number of skins varied each year, in 1558, a total of 731 skins were landed from Ireland. The invasion of Ireland by Cromwell in 1641 resulted in slaughter and destruction followed by a significant rise in wolf populations. By 1652, wolf-dogs were seized at ports for the purpose of hunting wolves. In 1653, organised hunts were arranged with a bounty of £5 for a male head and £6 for a female being paid. The attitude of the people had changed and new settlers wished to destroy all wolves, woodkerne (Irish rebels) and Tory. Woodland and scrub being the primary habitat of all three, efforts were made to reduce or destroy such areas. One by one, the isolated populations of wolves died out. This concerted effort resulted in the death of the last wolf in Ireland in approximately 1786.

Hickey uses three methods to estimate the wolf population in Ireland from 1492 onwards. The first method is based on the import of wolf skins from Ireland into the port of Bristol and other key trading ports. The number of skins imported declined at the close of the sixteenth century. To maintain the import level of wolf skins, a population of 600 to 1,000 wolves would have been necessary. The second assessment is based on the state of the Irish landscape around 1600 and human population levels. The total woodland cover around 1600 was 12.5%. A further 20% of the country remained uncultivated. The human population at this time is estimated at 1 to 1.5 million. The minimum available habitat for wolves should be approximately 27,000 km^2. A conservative estimate of population based on fifty packs of five to ten animals would give 250 to 500 wolves. A less conservative estimate based on average range size for a pack would give 390 to 780 wolves. The third wolf population estimate is based on bounty payments. The first is an extrapolation from kills in part of the West of Ireland giving a population figure for the whole island of 2,400. The second based on bounties paid between 1649 and 1656 gives a total population of between 450 and 800.

In his final comments the author discusses the possibility of the Irish wolf being a distinct sub-species. However, in the absence of any material from which to extract DNA this cannot be proven. He finds against the reintroduction of wolves in that the landscape has dramatically changed, public attitude would be negative and the cost prohibitive. Dr Hickey intends to continue with his research on this topic, so I look forward to more stimulating publications on the Irish Wolf.

John Whelan

(John Whelan (Sean Ó'Faoláin) is an emeritus Professor at UCD where he lectured on wildlife.)

In the footsteps of Augustine Henry and his Chinese plant collectors

Seamus O'Brien. Garden Art Press. 2011.
367 pages. Hardback. ISBN-13:978-1-87067-373-0.
£40.00

This book is essentially a biography of Augustine Henry, who as a young medical doctor joined the Chinese Imperial Maritime Customs Service in 1881 and subsequently became one of the world's most renowned plant collectors. After a period of training in Shanghai, his first field posting was to the remote town of Yichang in Hubei Province, Central China. This was an important customs post because at 1,770 kilometres inland from Shanghai, it stood at the limit of steam navigation on the Yangtze River. The central theme of the book gives considerable detail of Henry's extensive travels and plant collection activities in China. These were initially confined to Hubei Province but later extended to the south west of the country in the provinces of Sichuan and Yunnan, with shorter interludes on the tropical island of Hainan and in Taiwan. An idea of the remoteness of some of these postings can be gleaned from the vivid descriptions given and from the accounts of the journey of Henry's entourage to his final postings at Mengzi and Simoa in Yunnan Province.

At Yichang life was quiet and Henry's job monotonous. However, he found the landscape around the town interesting and enjoyed the spectacular scenery, especially in the Three Gorges region where the great new reservoir on the Yangtze now stands. These factors combined with his love of the countryside probably account for the development of his interest in the Chinese flora. Whatever the stimulus, he began to collect plants from the countryside around Yichang and in 1885, he dispatched over 1,000 preserved specimens to the Royal Botanic Gardens at Kew. In return he asked Sir Joseph Hooker (Director of Kew), for a list of determinations so that he could match botanical and colloquial names. At this stage of his career Henry knew little botany and lacked worthwhile texts. The collection which he sent to Kew attracted much attention as it contained many species which had never before been encountered. This continued to be the case with each batch of specimens which he sent from different regions of China. A detailed account, using botanical nomenclature, of the range of herbs, ferns, shrubs and trees which he found, is given throughout the book. Extensive lists of plants associated with Henry are presented in the appendices. The botanical nomenclature used throughout the book may leave many readers floundering, but gardening enthusiasts will recognise a large number as a high proportion have now become common garden plants. But this is not a textbook. What leavens it are the details of Henry's and the author's travels and travails which allow a genuine sense of the former's personality to emerge.

By the mid 1880's, Henry was keen to extend the range of his explorations and upon the intervention of Sir Thisleton-Dyer (then Director of Kew), he was granted six months leave. His plant collecting activities extended further inland to the mid

Yangtze region around the town of Badong. In the lowlands of this region he found the indigenous vegetation greatly disturbed, but in the mountainous areas the virgin forests contained a rich flora. It was in this region that he first found the living "fossil trees", *Ginkgo biloba* and *Metasequoia glyptostroboides*. At other locations too, he collected material from primeval forests, notably in the mountainous region of Hainan, in Southern Taiwan and in the lowland tropical forests of Yunnan. Other areas of Yunnan he found to be dreadfully barren and totally deforested. So rapid was the rate of forest exploitation in parts of China at this time, that, in his opinion, much of the native flora would be extinct within 50 years.

In writing this book the author has drawn copiously upon archival material; upon Henry's correspondence, notes, scientific writing and plant collections. An unusual feature is the on-the-ground research of the author, who over 100 years after Henry had left China, led a number of excursions to retrace Henry's Odyssey. This was not just to revisit the places which he had traversed, but also, to locate at these sites some of the species which Henry was first to collect. An account of the forays of the author's parties is interwoven with Henry's experiences to bring the picture, more or less, up to date. In some respects this second coming may have been quite fortunate because, in places, Henry's predictions concerning the fate of the native flora have come to pass. The author and his party found that in areas near Yichang, the native flora had been totally stripped. In other areas the clarity of the landscape has been diluted by smog. Much of the landscape around the Three Gorges has now changed forever as the massive new dam on the Yangtze reached its' maximum level in 2009, inundating much of the surrounding area. The author's team will be the last group to collect specimens of the flora over much of the area which Henry, in his initial years, traversed. As against all of this, the book emphasises that there are now more than 100 botanic gardens in China, all of which are involved in the preservation and conservation of the nation's rich flora. In addition there are very extensive reserves embracing forest and non-forest ecosystems.

Besides all of the geographical, landscape and floristic detail, this book sheds much light upon Henry's character and particularly upon the personal features which made him such an adventurous and successful plant collector. Initially, at least, the answer lay in his love of outdoor activity, his enormous energy and his generosity. His botanical expertise was poor at first and did not improve significantly until he had spent some time at Kew. His travels and access to the remote countryside were advanced by his fluency in Chinese. He was generous with his time, knowledge and expertise. As a result, other explorers such as Antwerp Pratt and Ernest Wilson sought him out. To the former he gave use of the native plant collectors whom he had trained and to the latter he gave directions as to where to find the Handkerchief tree *(Davidia involucrata)* (Figure 1) in Sichuan Province. The extent of his generosity is apparent from the fact that in the later stages of his stay in China he was collecting multiple specimens of each plant (sometimes up to 10) for dispatch to curators in China, England, Ireland, the United States and other European countries. In return he neither sought nor received any remuneration except for occasional expenses with which to pay collectors, porters and guides. This book also records the low point in Henry's life which occurred upon his return to China after the death, in 1894, of his wife Caroline.

Figure 1: *A view from under the branches of a handkerchief tree (in full bloom in June 2012) at the National Botanic Gardens in Glasnevin, Co. Dublin. One of the first trees of its species to be planted in Europe as a result of Augustine Henry's botanical discoveries.*

When he finally departed from China in 1900 he had collected 158,050 herbarium specimens, of which 1,726 were newly discovered species.

As is apparent from this book Henry was a prolific letter writer. He developed correspondence with a great number of influential people; academics (Professor Charles Sargent, Harvard University), directors of botanic institutions (Sir Frederick Moore, National Botanic Gardens, Glasnevin), wealthy land owners (Sir Henry John Elwes) and nursery owners (Sir Harry Veitch). It is emphasised that Veitch was the only one of this heterogenous group of friends to benefit financially from his work and Elwes was the only one to provide him with relatively generous expenses when he was involved in field research for their book. It is striking that many of the people with whom he corresponded became staunch, lifelong friends. This ability to form lasting friendships is also apparent in the details of his return to London and eventually Dublin. His new friends in Dublin included academics, politicians and artists. The last chapter in this book is entitled "Henry the Forester". It gives some detail of his developing interest in forestry but is surprisingly subdued about his experiences at *École Nationale Forestière de Nancy*. There is however, a hint that he was lured away from his studies by Elwes in order to undertake the fieldwork for their *magnum opus,* "The Trees of Great Britain and Ireland", which was published between 1906 and 1913. It seems that it was while in America on this mission that Henry became convinced that Western American tree species would be more suitable for afforestation in Ireland than European ones. He appears to have concluded also, that European methods of silviculture were sub-optimal for Irish conditions. These views he made known in Dublin. In 1913 he returned to Ireland having been offered the Chair of Forestry at the Royal College of Science (now University College Dublin).

Henry is widely acclaimed and honoured for his work on the flora of China and for his contributions to forestry in Ireland. In relation to the former he is probably better known abroad than in Ireland. This book is another accolade to him and the author's input in retracing his Chinese itinerary lends additional authority to the narrative while bringing to light facts of Henry's personality which, heretofore were little known. The book is exceptionally well illustrated with maps, diagrams, sketches and photographs (old and new). Most foresters will enjoy reading about the adventures of one of the founding fathers of Irish forestry, but may not consider this book a prerequisite for their own library shelves.

John J. Gardiner
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Society of Irish Foresters study tour to Ontario 6 - 13 September 2011

On Tuesday, 6th September, 31 members of the Society of Irish Foresters departed Dublin for Pearson International Airport, Toronto to begin the 68th Annual Study Tour. The group was welcomed at Toronto Airport by our guide for the week, Mr. David Milton, Ontario Professional Foresters Association and President of the Ontario Lumber Manufacturers Association.

The province of Ontario has 71 million ha of forests (65% of its land area), of which 52 million ha is classified as productive forest. Although annual yields are much lower than in Ireland, Ontario's forests produce approximately 62 million m^3 annually. The current value of Ontario's forest products sector is €15.3 billion per annum.

Crown forests comprise 81% of the forested area, parks and protected areas 9% and other lands 10%. Forest types range from the deciduous forest of the Niagara Peninsula area, through the mixed forest of the Great Lakes-Saint Lawrence region in central and northwestern Ontario, to the conifer dominated boreal forest of the north. Ontario's most common tree species are black spruce (*Picea mariana* (Mill.) Brit.) (37.3%), poplar (*Populus* spp.) (20.8%), jack pine (*Pinus banksiana* Lamb.) (11.7%), white birch (*Betula* spp.) (7%), balsam fir (Abies balsamea (L.) Mill.) (4%), white pine (*Pinus strobus* L.) (3%); while sugar maple (*Acer saccharum* Marsh.), the species most associated with Canada, comprises just 4% of the total.

This was the Society's fifth tour in North America. Inevitably, comparisons will be made with Oregon/Washington (1992), British Columbia (2000), New England (2004) and California (2008). The defining quality of this year's tour was the confident professionalism of the foresters we met during our 2,770 km journey through southern Ontario. These foresters displayed great pride in their profession and an in-depth knowledge of silviculture and of the many issues currently confronting forestry in Ontario.

David Milton was the perfect tour guide. He selected interesting forests to visit and excellent foresters to meet us. Throughout the tour he worked tirelessly to ensure we got a fascinating insight into Ontario's forests and related industries. The Society is deeply indebted to him.

Pat O'Sullivan, Tour Convenor

Tuesday, 6th September

The most striking difference between forestry in Ireland and Ontario is scale. The land area of the province of Ontario is 107.6 million ha in extent, whereas Ireland is only 7.1 million ha. Close to two-thirds of its land area is forested; it has 17.5% of Canada's forests and more than 2% of the world's forests. The extent of forest cover soon became apparent as we headed past Caledon, through a landscape similar to that described by the acclaimed Canadian writer Alice Munro (see Trees, Woods and

Literature). A native of Wingham – approximately 95 km to the west – the forests and landscape of southwest Ontario are ever-present in her short stories.

The group headed north from Pearson International Airport to visit a demonstration plot in Dufferin Forest, one of 12 tracts in this 1,050 ha forest. This demonstration area has a variety of thinning selection systems, mainly in mixed-age red pine (*Pinus resinosa* Ait.) plantations, which are designed to encourage natural understorey development. Caroline Mach, our leader for the afternoon, explained the different selection thinning trials being studied there.

While recreation and non-wood forestry are extremely important in Ontario, approximately 68% of the province's forests are managed intensively; the remainder comprises mainly sparse areas of non-commercial forests. The commercially managed forests comprise conifers (28%) and deciduous woodlands (10%), while 28% are classed as mixed species forests.

Dufferin Forest was a wonderful introduction to Ontario's forest philosophy. Here the public is invited to walk through the trial plots and view the various thinning methods – a confident gesture by the county foresters who are not afraid to engage with stakeholders. Dufferin County began its afforestation programme after purchasing the first tracts of land in 1930. Its forest management regime is highly regarded and has received a number of national awards, including the Forest Stewardship Recognition Programme award.

The first stop featured red pine, a species similar to Corsican pine (*Pinus nigra* Arnold), which was planted in 1967 at 1.8 m spacing and received a first thinning after 30 years, followed by a thinning every 10 to 15 years thereafter. Maple (*Acer* spp.) and ash (*Fraxinus* spp.) regeneration is also encouraged.

The second stop also featured red pine with a similar thinning regime but there the white pine (often called Weymouth pine) 'dotted' around the plantation was being encouraged to regenerate. The white pine was heavily exploited by Ontario's early settlers for use as ships masts, and now only a few groves remain, so Dufferin's foresters are giving this species a "helping hand" to regenerate. It tolerates a mix of shade and sunlight so it should regenerate well here.

Further along the walk we stopped at a plot which contained predominantly hardwood species. Here, red oak (*Quercus rubra* L.) – now the official tree of Dufferin County – forms 60% of the crop with a good mix of white ash, American beech and sugar maple.

Red oak, unlike Irish oak (*Quercus robur* L. and *Q. petraea* L.) is semi shade tolerant, but according to our guide has difficulty in competing under the canopy of maple, beech, and ash. Fire is often the regenerative catalyst if nature or man intervenes. Wildfire removes the leaf litter layer and the acorns then germinate in the exposed soil condition, whereas maple, ash and beech fail to naturally generate under such conditions.

The forest management objectives here are to provide Dufferin County with a positive financial return, to create and enhance recreation facilities, heritage protection, wildlife habitat, biodiversity and water control.

In Ontario foresters discuss yields and growth performance in terms of basal area (BA) rather than yield class (YC). BA averaged around 10 m^2 ha^{-1} in some of the red pine plots at year 30, which would suggest a YC of little more than 2.

It was interesting to hear Dufferin foresters discuss the economic, social and ecological benefits of these low yield class plantations, as well as their role in climate change mitigation. This contrasts with forest policy in Ireland which precludes planting conifers on most unenclosed sites and all sites with less than YC 14 potential. After exploring further trial plots and tree species as well as ground vegetation – including trillium, wild columbine, star flower and the noxious and dangerous weed, poison ivy – the group then headed to Gravenhurst.

Overnight - Marriott Residence Inn, Gravenhurst. *Donal Magner*

Wednesday, 7th September

From Gravenhurst, we headed northeast for 70 km to enter Algonquin Provincial Park, which covers an area of 763,555 ha including water – almost equivalent in size to Ireland's entire forest estate. Since 1974 the park has been managed by the Algonquin Forestry Authority (AFA), which is the Crown agency responsible for multipurpose forestry including silviculture, wildlife and fish management, research and wilderness management. Our guides for the Algonquin tour were Keith Fletcher, Karl Corbett and Chief Forester, Paul Cummins.

Figure 1: *Caroline Mach (right) explains the thinning regime in a red pine demonstration plot, Dufferin Forest.*

While harvesting appears to be low key, the AFA has a commercial mandate and is required to be self-sufficient, so production forestry is a key objective of the AFA. The revenue generated pays for the running costs of the AFA, in addition to all operations including forest regeneration, tending and associated operations. Not all logging companies and wood processors agree with the AFA approach. When the NPA was established, a master plan called for the 18 existing timber licences. The AFA has a sustainable forest management policy and the park's forests are certified to Canada's national forest certification standard (CSA). We entered the park at the western section, which contains maple (*Acer* spp.), beech, yellow birch (*Betula alleghaniensis* Brit.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.). The eastern section contains white and red pine, poplar and white birch.

The hardwoods are managed according to the selection system whereas the uniform shelterwood system is used to manage the conifers in the eastern section of the park. Certified tree markers select the trees, which are conspicuously marked with paint, so that harvesting operators can easily identify them. Trees are removed so that ground cover is maintained at all times. Interestingly, there is no evidence of clearcutting, except in small areas when species like jack pine, white birch and poplars (*Populus* spp.) dominate.

Our visit included a number of stops at thinning treatment and harvesting sites although we missed a harvesting operation on the Rock Lake Road, where a sequence of harvesting treatments have been in operation over a number of decades.

The results of silvicultural treatments where shelterwood systems were in operation with both shade tolerant and intolerant species were shown at the first stop. Less than a third of the park is available for forest harvesting on a periodic basis, with activity on approximately 1.5% of the area in any one year.

As the tour progressed from west to east, the three silvicultural systems practised in the Algonquin were discussed. Selection and shelterwood methods are applied to 95% of all harvested areas with small-scale clearcuts in only 5% of the park's forests.

Shade intolerant species such as poplar, red pine, jack pine and white birch are best suited to a partial clearcut as they need plenty of sunlight. White pine, yellow birch and red oak need a mixture of shade and sunlight so they can be managed according the uniform shelterwood system. This allows a series of two or more cuts over a period of 10 to 30 years in a maturing stand and thus ensures continuous cover.

Maple, beech and hemlock on the other hand are managed using the selection system. This "uneven-aged" system allows the retention of a largely intact canopy suited for shade tolerant species which are capable of germinating and developing to maturity in the shade of larger trees.

Both silvicultural systems require intensive management. The tree markers select trees not only to ensure correct volume removal but also they must think ahead to allow the next layer or tree storey to emerge. The harvester must fell and remove trees with minimal damage to young saplings, which will form the next rotation crop.

These systems, together with the AFA's conservation policy, demonstrate the rationale behind the enforcement of a strict logging licencing system. There was heavy exploitation of the forests particularly during the 1920s and 1930s and even up to the 1960s when many logging companies adopted a "fell the best, leave the rest"

Figure 2: *Taking the Hardwood Lookout Trail, overlooking Smoke Lake, Algonquin Provincial Park: Izabela Witkowska, John Guinan, Pacelli Breathnach and Donal Magner.*

approach.

The group took a break for a pleasant lunch in the Arrowhon Pines Resort before continuing through Algonquin and finally taking a stroll through the Hardwood Lookout Trail, overlooking the beautiful Smoke Lake.

Traversing undulating terrain, this 1 km walk has several numbered posts which explain the species and the ecology of the hardwood forest with its rich variety of maples – striped, red and sugar – yellow birch, black cherry (*Prunus serotina* Ehr.) and beech. Some conifers, such as eastern hemlock, remain but the once plentiful white pine has virtually disappeared over the years. The Hardwood Lookout Trail is just one of 14 interpretive trails in the park and along with its other activities, AFA's foresters demonstrate clearly that economic, environmental and social forestry can be compatible.

Overnight - Marriott Residence Inn. *Donal Magner*

Thursday, 8th September

The party departed Gravenhurst and headed for the Haliburton Forest and Wildlife Reserve, a 40,000 ha privately owned forest in Ontario's cottage country which combines private forest ownership and management, recreation, forest research and value added wood products. The forest was acquired 53 years ago by the father of the present owner, Peter Schleifenbaum. The forest soil is sandy with a low water holding capacity; in summer the trees occasionally suffer stress as a result. Frost may commence towards late August and is often followed by snow, which can last until April.

Forest management and output are dictated to a large extent by the demands of the sawmill and in turn, the secure supply of logs from the forest to meet the mill's responses to ever changing market demands increases the profitability of the mill. The sawmill has a through-put of 40,000 t $year^{-1}$ and employs 16 men working a 10-hour shift four days per week for 50 weeks. In the forest 60% of the trees are suitable for processing at the mill which operates a 45% recovery rate. On arrival at the mill, the bark is removed from the logs and converted to mulch which is sold to amenity and horticultural businesses throughout Ontario. The market is volatile and tree species can quickly gain or lose popularity. Dave Bishop, the general manager at the mill explained that eastern hemlock was almost discarded some time ago and now it is the most profitable species processed.

Innovation and research is encouraged at Haliburton, an enterprise which receives no government support. Product innovation is driven by market demands. New products are tested in the market and if they are not well received then production is quickly abandoned. We were introduced to Jon Schorman a Ph.D. student from the University of Toronto, who is working on biochar - a charcoal created by pyrolysis of tree biomass. It is hoped that this research will lead to future earnings from carbon credits in agriculture when the biochar is spread at the rate of 1 to 1.5 t ha^{-1}.

The wildlife reserve section of the enterprise operates a large multi-user recreation and resource management facility. There is a network of 300 km of trails which vary from wide, level, hard-packed and rolled pathways, to rocky muddy paths for the more adventurous. Five shelter cabins spaced over the reserve provide a place to rest or view the scenery. As this is a wilderness area, visitors are given instruction in map reading prior to setting out.

Almost 65% of the profit at the Haliburton Forest and Wildlife Reserve comes from the recreation section and the remaining 35% is returned by timber processing. The business plan aims to increase the profit contribution from the timber processing to 70% of group profits by 2017.

The party then left Haliburton Forest and travelled to Fortune Farms demonstration forest, one of the many partnership forests in the Eastern Ontario Model Forest. We were welcomed to this maple syrup producing forest by the owners Ray and Ruth Fortune and general manager Mark Richardson. The Fortunes purchased the farm in 1972 and have successfully managed their enterprise to improve maple sap production. Their careful efforts have also created a healthier and more diverse forest that provides wood for fuel, a habitat for wildlife and numerous recreation trails.

Since the late 1800's, settlers have tapped the maples in the mixed hardwood forests on this farm. Good forest management has enabled the Fortunes to double their sap production since 1992. They now produce 5,100 L of syrup per annum. It requires almost 40 L of maple sap to produce one litre of syrup. Their management regime is centered on the conversion of fields and conifer plantations back to native, mixed hardwood forest. Forest restoration in the area provides many benefits to landowners as it increases species diversity and filters pollutants from the air.

The trees are tapped and connected by a network of tubes and pipes which carry the sap to the automated storage and evaporator system. The sap flows continuously into the evaporator. As water evaporates, sap with a higher sugar content is produced and this is then pumped along until it reaches the finishing pan where the maple syrup is collected and drawn off at regular intervals. In the forest we were shown how mixed hardwood stands comprising trees of all ages can be thinned to improve syrup production as well as timber and wildlife production. The thinning opens up a stand, thus reducing competition for light and nutrients and creating space for the maples to develop large crowns. Trees with large crowns produce a sweeter sap than trees with poorly developed crowns.

The owner, Ray Fortune, believes the best time to begin thinning a sugar maple stand is when the maples are between 2.5 cm - 9.0 cm DBH. At this stage the optimum spacing is 2.5 m. Twenty years later, when the trees have reached polewood stage (10 cm to 25 cm DBH), a further thinning is carried out which leaves healthy maple trees approximately 5 m apart. The third and final thinning takes place when the trees are mature and at 10 m spacing; this is considered the ideal spacing for sap production. Trees are tapped for sap when they reach 25 cm DBH.

The initial investment to start up a sugar maple enterprise is substantial. The Fortune's farm has 57 km of tubing and 14 km of pipeline, in addition to the buildings and evaporators. In this part of Ontario the threat of severe weather is ever present. In 1998 an "ice storm" almost destroyed the entire enterprise. All the tubes and piping were buried under several feet of ice by a storm just before the start of the annual tapping season, which is a mere four- to five-week window in early spring. A huge effort by the entire family working day and night cleared the ice so that sap collection could commence on time!

This visit covered two quite different but profitable business enterprises, which were based entirely on land and its produce and which created no environmental damage. This provided a memorable day for foresters who were all too familiar with the concept of trying to use land for economic gain while preserving it for future generations.

Overnight - Lord Elgin Hotel, Ottawa. *Frank Nugent*

Friday, 9th September

We departed our hotel in downtown Ottawa and travelled north-westwards through the Ottawa Valley on Highway 17 to North Bay, a distance of 350 km. The Ottawa Valley follows the Ottawa River and forms the boundary between eastern Ontario and western Québec. The first stop was at Renfrew County Forest where we met our hosts Jeff Muzzi, Head of Forestry Services, and Lacey Rose, County Forester. Renfrew County Forest consists of 6,400 ha in 51 different tracts. The County Forests are considered working forests where forest management activities take precedent over other activities. Interestingly, Renfrew County was settled by Irish settlers in the 19th century. Jeff Muzzi lives between the towns of Tramore and Killaloe, while names like Meath and Connaught are also to be found!

The theme throughout our visit to Renfrew County was forest restoration. The forests of Renfrew were cleared by earlier settlers to create land for agriculture. However, due to the sandy nature of the soil the land soon degraded and many homesteads were abandoned. The county began acquiring these lands in the 1950's and set about improving soil conditions and reducing erosion through reforestation. Renfrew County Forest has both plantation and natural forests.

The tract we visited was a plantation of red pine with some white pine which was planted for regeneration purposes between 1950 and 1953. Spacing was approx 1.8 m × 1.8 m. It was thinned in 1980, 1992, 2010. There will be two further thinnings. The first thinning involved removal of every 5th line with selection between the lines. The current stocking is 300 stems ha^{-1}. The management objective is to convert the forest from red pine to white pine using the continuous cover uniform shelterwood management system. Red pine would have to be replanted whereas white pine, being more shade bearing, will regenerate naturally under the red pine. The plan is to open the canopy by one third at each thinning. Thinning begins when the basal area of the crop reaches 36 m^2 ha^{-1}. Each thinning aims to reduce the basal area to 24 – 26 m^2 ha^{-1}. This regime strikes a good balance between a sufficient opening up of the crown to allow white pine to germinate while allowing sufficient growing space to the remaining crop. The red pine crop is used mainly for transmission pole production. Up to 25 years ago hardwood management consisted of taking the biggest and the best, while this has now changed to leaving the better growing trees for regeneration. Market conditions also determine whether to thin in a particular year. The poles are currently making €50.00 (CAN$65) m^{-3} delivered. For later thinning the price will rise to €116.50 (CAN$150) m^{-3} delivered. Approximately 75% of the produce from the next thinning will be poles. Harvesting must take place before snow and heavy frost as the pine becomes too brittle when the timber is frozen. Some mechanical ground preparation is carried out after thinning to improve natural regeneration. Although the forest is FSC certified, some chemical control of vegetation is used to remove woody weed competition.

Following lunch in Pembroke we headed towards the Canadian Institute of Forestry in Mattawa. Fortunately, we were joined on the bus by Al Stenson, Scott McPherson and Fred Pinto from the Institute as further up the highway we were delayed two hours by a major truck fire. As a result we had to cancel our field visits to Nipissing Forest to see examples of the uniform shelterwood system and single tree selection system. Nevertheless we enjoyed a wide ranging discussion with our host on the work of Institute. Their research work aims to provide scientific underpinning of the forest management practices in the area with the objective of improving stand quality.

Their main research objective is to assess the impact of natural forces on the forest and then to try to replicate these results through management practices. Examples are the age distribution of the forest as a result of the impact of fire. Three silvicultural systems are practiced – hardwood selection/shelterwood, pine shelterwood and clear-cut with standards. Approximately one third of harvesting is carried out using each of these systems. The allowable harvest in Nipissing Forest is approximately 707,000 m^3. However, due to weak market demand for low grade hardwood pulp, the actual cut is only 420,000 m^3. In addition to supplying timber, forest management practices must also provide for the fauna of the forest with particular reference to the feeding conditions of a large range of animals such as black bears. A forest management company, Nipissing Forest Resource Management Inc., manages the forest. It is a partnership of local forest industries. It has been issued a Sustainable Forest Licence and is charged with implementing the forest management plan which is prepared every 10 years. It costs approximately €750,000 to prepare and complete an extensive public consultation.

Our hosts also gave us a comprehensive overview of forest fire problems in Nipissing Forest where up to 40,000 ha is burned each year. Judicious use of 'water bombing helps to "break the back" of larger fires, but the real work of controlling fires is carried out by ground-based fire crews of four. These crews are employed fulltime on a seasonal basis and are highly trained professionals. They can be deployed to other parts of Canada if the fire season is quiet in Ontario.

Overnight - Hilton Hampton Inn, North Bay. *Pacelli Breathnach*

Saturday, 10th September

Early on Saturday morning our coach headed north-west for Sudbury Forest near

Figure 3: *Lacey Rose (centre), Renfrew County Forester and Jeff Muzzi, Head of Forestry Services outline the advantages of the Uniform Shelterwood Management System in Renfrew Forest, Ottawa Valley.*

Sturgeon Falls. Here we were welcomed by Mr. Ron Luopa, Operations Manager at the Vermillion Forest Management Company, who took us further west to see some natural regeneration of fire origin pine on an outwash plain. This area, which lies north-west of Sturgeon Falls, is the heart of the "transition forest zone" where the species mix changes from mixed deciduous and conifer to the boreal species, such as white pine.

Sudbury Forest has a forested area of almost 75 km^2 growing, for the most part on fertile, heavy textured soils. The annual cut is 22 million m^3. However, less than 60% of this is harvested as the demand for timber in the USA, their main market, is extremely depressed at the moment.

The system of tenure in Sudbury Forest is interesting. These are Crown Lands which are licensed to eight separate logging companies. The licences are generally granted for a period of five years, although 10-year licences are now becoming popular. The licensees have established a co-operative called Vermillion Forest Management Company (VFM), which is responsible for the management and silviculture of the crops on the entire forest area. VFM prepares a 10-year management plan for Sudbury Forest. During this process it engages in extensive consultation with the public, as the forest is heavily used for recreation, and with the licensees. The plan is then submitted to Ontario's Department of Natural Resources for approval and generally, following some tweaking and further consultation, the plan is approved. This entire process usually takes two years to complete.

When the management plan is approved, VFM then monitors how the licensees have performed and can impose non-compliance fines for breaches of the conditions attached to the management plan. An independent auditing company, which has the power to renew or revoke licences, oversees the entire operation and every five years it adjudicates on compliance levels. In addition, VFM must work closely with the local Citizens Committees. These stakeholder groups do not have a veto on VFM's operations but they do exercise a powerful influence over the day to day management of the forest. Overall, the current system is a far cry from the early days when loggers worked on the principle of - "take the best and leave the rest".

In Sudbury Forest, fire is the main determinant of the type of crop which has developed there. White pine, which has very thick bark and grows very tall, is dependent on forest fires for regeneration. Lesser trees, such as poplars, aspens and birch, are scorched and killed whereas a sufficient number of the tall white pine are left to produce seeds for the next rotation.

In establishing crops on these fertile soils, the foresters try to mimic nature by using a range of tools including prescribed burning (to a limited extent) and chemical site preparation with skidder mounted sprayers which apply 8 L ha^{-1} of Roundup in year two. During year four there is usually a further "chemical tending" in order to control competition from poplar, red maple, raspberry and other herbaceous plants. In year six, areas of weak regeneration are in-filled with red pine.

Given the rather intensive herbicide treatment regime employed in this forest, there was some surprise that it was FSC certified. The foresters defence is that, on these fertile, heavy soils it is not possible to re-establish white pine crops in the absence of some chemical intervention during the early stages of the rotation. Mechanical site preparation is not widely practised here as the resultant soil disturbance encourages excessive growth of grasses and woody weeds. Currently, the market for pine is quite weak, whereas poplar and birch are increasing in popularity due to demand from the particle board industry.

Overnight - Stone Gate Inn, Orillia. *Pat O'Sullivan*

Sunday, 11th September

Following a free morning in the lakeside town of Orillia, we headed west to Simcoe County Forest. There we were met by the Chief Forester, Graeme Davis who explained that the Oro moraine was once heavily forested, but after logging in the 19th century the area had turned into a dust bowl as the top soil dried up and was blown away. There were problems with flash floods, water erosion and ground water contamination. The site became an "Agreement Forest" in 1922 and has been managed through an agreement with the Ontario Ministry of Natural Resources since 1996.

The Council continues to acquire poor land with profits from the sale of timber. Land costs €2,500 to €3,000 ha^{-1} and in the past five years it has purchased almost 1,000 ha. Simcoe County Forest is the largest and most productive municipally owned forest in Ontario. The total area of the forest is now 12,500 ha, of which 50% is plantation, 80% of the forest is productive and 20% is wetland. The annual revenue is €775,000.

The area we visited was the Hendrie Tract, which was named after the family that once lived there. It was planted with red pine in 1962. The current basal area of the crop is 40 m^2 and it is proposed to thin to reduce the basal area to 30 m^2. The thinnings will be sold for transmission poles. The rotation length here is 90 years. As areas are clear felled, it is hoped that they will revert to natural forests and that white pine and oak will regenerate. White pine was the major component of the original forest because the native people used fire to clear areas for agriculture and white pine regenerates quicker than red pine after fire. Honey fungus (*Armillaria mellea*) is also a major problem on the site.

The public is very supportive of the forest and profits from the forest are ring-fenced for reinvestment in the forest and to improve recreational facilities. The forest is popular with a wide range of users, from mountain bikers to hunters, but there is little conflict between the different groups. Simcoe County Forest was awarded FSC status in 2010.

As we drove through Ontario we often noticed lakes which had been created by beavers. The tell-tale sign was the presence of the beaver lodge. It is built above the water level so that the beaver can enter unseen from under the water, while at the same time providing a dry home for the family. The beaver is the national animal of Canada. It was once an important element of the economy, as it was hunted for its fur, but it is now protected and a much loved species.

Late in the evening we headed south for the town of Orangeville and dinner in the Greystones Inn. We then continued on towards our overnight accommodation in the university city of Guelph, where the internationally acclaimed economist J.K. Galbraith began his career studying agricultural economics.

Figure 4: *The "Coillte group" in Simcoe County Forest, near Orillia, Ontario.*

Overnight - Best Western Royal Brock Hotel, Guelph *John McLoughlin*

Monday, 12th September
The Arboretum of the University of Guelph was the first stop of the day. The group explored the well laid out arboretum on a self-guided tour. The arboretum was established in 1970 and features tree species which are native to southern Ontario as well as non-natives tree species. It also features old growth forest, protected wetlands and some beautiful sculptures, including a two piece metallic sculpture, called 'A Tribute to Nahneebahweequay', one part of which takes the distinctive form of Queen Victoria.

Mr Martin Neumann, Supervisor of Terrestrial Resources with the Grand River Conservation Authority (GRCA) joined the group at the arboretum. The Grand River flows from Dundalk, Ontario to enter Lake Erie at Port Maitland, a 300 km journey in a catchment of approximately 7,000 km^2. Close to one million people live in this catchment area and they depend on the Grand River and its tributaries for their water supply and to attenuate the need for waste water treatment plants. The GRCA manages water and other natural resources on behalf of the municipalities in the Grand River catchment.

Martin Neumann guided the bus south from Guelph to Brantford via Paris, Ontario through the centre of the Grand River watershed. Before leaving Guelph, the tour group took a quick look at an intercropping research plot at the Agroforestry Department of the University of Guelph. Annual crops, such as corn, are inter-planted with black walnut (*Juglans nigra* L.) and ash when the trees are small. As the trees mature the annual crops of corn are replaced with grass for hay production. Results to date show a net gain for both the annual crop and the trees but there has been no uptake by farmers as yet.

The bus stopped briefly at Guelph Lake Reservoir which is known locally as "fake lake". The annual precipitation in the catchment is 84 cm (33") and mostly falls as snow during the winter months. This reservoir is one of the watershed's network of reservoirs which are designed to capture snow to augment water supplies during the drier summer months. The reservoirs also serve to prevent flood events. As part of flood control measures, the GRCA has a network of water gauges through the system which collect real time water level information. These real time data are available to the public on www.grandriver.ca [Accessed July 2012] and are widely used by fishermen and canoeists.

En route to lunch at the Olde School Restaurant in Brantford, we passed the Rotary Forest. The planting of this 40 ha green field site by volunteers was sponsored by Guelph Rotary Club. The Rotary Forest is one of a number of partnership projects that the GRCA organises to encourage tree planting within the watershed. Another popular scheme is the *Trees for Guelph* project aimed at getting students to plant trees in their school yards and on public lands. To date almost 100,000 trees have been planted under this scheme.

As the bus travelled south, Mr Neumann described a number of projects that the GRCA has developed with the aim of improving water quality in the watershed. Grants are available to farmers to create livestock exclusion zones along streams in order to protect and enhance cold-water trout habitats. He described how, in the past, planting stopped 10-15 m back from rivers but now most of the planting is done in this 10-15 m corridor to ensure that stream water temperatures stay at a level suitable for the cold-water trout. The GRCA also provides workshops for landowners and a free extension service of forestry and pasture management.

South of Cambridge, Ontario the bus entered the Carolinian forest zone. Typical Carolinian forest tree species are oak, hickory (*Carya* spp.), walnut, butternut (*Juglans cinerea* L.), sassafras (*Sassafras albidum* (Nutt.) Nees), blackgum (*Nyssa sylvatica* Marsh.), and the tulip tree (*Liriodendron tulipifera* L.). The GRCA has purchased remnants of Carolinian forest and now owns the largest continuous Carolinian forest in the watershed. Whenever funding is available the GRCA purchases additional conservation land but only after proving that the land can be maintained by the GRCA in perpetuity. The authority aims to maximise biodiversity from its 19,800 ha of reservoirs, park and reserve.

After lunch the group visited a black oak (*Quercus velutina* Lam.) savanna restoration project in Brant County. Savannas are generally tall grass prairie communities with 10-35% tree cover. These communities are now very rare in

Figure 5: *Journey's end - Frank Nugent, Willie McKenna, Michael Doyle and Gerhardt Gallagher at Niagara Falls, Ontario.*

southern Ontario as a result of European settlements. Savanna is an anthropogenic habitat having originally been influenced by First Nation people[1]. These habitats are fire dependent. Martin and his colleague Kevin Tupman, Natural Heritage Specialist with the GRCA, described the restoration project and related that the aim of the project was to recreate a 20 ha black oak savanna.

The restoration site had been used for Scots pine (*Pinus sylvestris* L.) Christmas tree production. The remaining Scots pine trees on site had prevented the oak savanna from re-establishing itself. The project involved the removal of invasive exotics such as the Scots pine, European buckthorn (*Rhamnus cathartica* L.), Tartarian honeysuckle (*Lonicera tatarica* L.) together with a regime of prescribed burns. Black oak, a Carolinian species, is the quintessential savanna tree in Ontario. Typical savanna plant species include; butterfly weed (*Asclepias tuberosa* L.), sky blue aster (*Symphyotrichum oolentangiense* (Riddell) Nesom), heath aster (*Symphyotrichum ericoides* (L.) Nesom), wild bergamot (*Monarda fistulosa* L.), and Canada golden rod (*Solidago canadensis* L). Animal species typically found in savanna habitat include; red headed woodpecker (*Melanerpes erythrocephalus*), hog nose snake (*Heterodon nasicus*), racoon (*Procyon lotor*), red squirrel (*Sciurus vulgaris*), coyote (*Canis latrans*), red fox (*Vulpes vulpes*), rabbits (*Sylvilagus* spp.), European hare (*Lepus Europaeus*), eastern chipmunk (*Tamias striatu*s) and flying squirrels (*Glaucomys sabrinus*). Very little wildlife is lost in the prescribed burns fire, which have been successful in encouraging savanna plants to appear in the under storey.

We departed Brant County and headed east to Niagara Falls. A highlight of the tour was viewing the floodlit American and Horseshoe falls.

Overnight - Skyline Inn Hotel, Niagara Falls. *Clodagh Duffy*

[1] The collective term First Nation people describes various aboriginal peoples in Canada, apart from the Inuit or the Métis. It came into common usage during the 1970s and 1980s to avoid use of the word "Indian" which as well as being considered offensive was recognised as being a misnomer.

Tuesday, 13th September

The group departed Niagara and travelled along the Niagara River Parkway, the tree-lined parkway which contours the Niagara Gorge. We crossed the Beamsville Bench and entered Fruitland County, which is dotted with apple (*Malus domestica* Borkh.), peach (*Prunus persica* (L.) Batsch) and grape (*Vitis vinifera* L.) orchards and is home to many well known vineyards.

Our first stop was at Woodend, located just south of the town of Niagara on the Lake. Here we were met by our guide Dan Drennan, a forester with the Niagara Peninsula Conservation Authority (NPCA). He explained that the NPCA's main focus is on environmental protection and preservation and watershed management. It includes community outreach activities and the restoration/extension of forest areas through land acquisition and public ownership.

His job is to oversee woodland management plans to ensure they comply with standard practice and to supervise the implementation of these plans. His main challenge is to encourage native trees and shrubs and to protect endangered species such as Sassafras, oak species, ash, and other light demanders which are being threatened by the more freely regenerating shade bearing species. This site is classified as a Carolinian Forest[2] and is typical of the many small, fragmented woodland blocks in this part of southern Ontario. It forms part of a trail network and is managed almost entirely for public recreation.

The deep, moist fertile soil supports a very diverse habitat of trees, flora and fauna. The forest canopy is composed of sugar maple, white ash, bitternut hickory, ash, red oak, white swamp oak, pin oak, bur oak, sassafras, aspen, cotton wood, tulip tree.

Single tree selection, at 10- to 20-year intervals, is the approved silvicultural system in the management plan. The plan also encourages the retention of old growth trees. Local interested groups favour low intensity management and oppose any tree felling. As a result the woodland has a dense canopy containing a high percentage of dead wood. Regeneration of light demanding species is very restricted and ground flora is sparse. Foresters are concerned that if they are not allowed to implement tree selection and felling plans, then light demanders such as the oaks, ash, hickory and aspen will soon be replaced by beech and maple species.

The main threats faced by the Carolinian forests are:-

- the fertility of the soil results in pressure from agricultural development which threatens the survival of the woodlands and its associated flora and fauna;
- the emerald ash borer, from China, if left uncontrolled may kill all ash trees;
- the extinction of rare plants, trees, and birds by a lack of protection measures.

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2 Carolinian Forest is a name given to woodlands in a zone south of a line from Toronto to Grand Bend on Lake Huron. Deciduous hardwoods are the main tree species, consisting mainly of oaks, maples, beech, cotton wood, ash, sassafras, aspen, tulip tree and many more. This zone is species rich both in trees and ground flora, 40% of the national list of endangered species occurs in this zone. The soils are fertile and agricultural and residential pressures have threatened the natural woodlands' wildlife habitats. Only 10% of the original forests remain. Conservation is now a top priority in this zone.

A trail through the centre of the woodland stimulated a discussion on trail specifications and safety. The trail was quite rugged with many obstacles such as surface roots, boulders and deep depressions. At a number of locations it overlooked very steep drops. The forester explained that this trail would be classified in the "low to moderate usage" category and was used mainly by experienced walkers. If the trail was classified as "high usage" it would be upgraded and the danger spots would have protective barriers.

At the end of the trail we boarded our bus for lunch in the historic town of Niagara on the Lake and then headed north to Toronto's Pearson International Airport and our overnight flight back to Dublin.

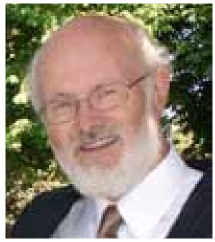
Michael Doyle

Tour Participants

Pacelli Breathnach, P.J. Bruton, Richard Clear, James Crowley, Bob Dagg, Michael Doyle, Clodagh Duffy, Ken Ellis, Jerry Fleming, Gerhardt Gallagher, Tony Gallinagh, Sean Galvin, John Guinan, Mark Hogan, Kevin Kenny, Donal Magner, Tony Mannion, Willie McKenna, John McLoughlin, Kieran Moloney, Stephen Moore, Liam Murphy, Frank Nugent, Dermot O'Brien, Michael O'Brien, Paddy O'Kelly, Tim O'Regan, Denis O'Sullivan, Pat O'Sullivan, Trevor Wilson, Izabela Witkowska.

Obituaries

Sean Hayes
1942 – 2011



Sean Hayes passed away after a short illness on the 3rd December 2011. Sean was born in Limerick on the 7th January 1942, the eldest son of Pat and Mary Hayes. Sean spent all his childhood in Westfields and attended school at the C.B.S. in Limerick.

Sean graduated with honours from UCD in September 1968. He joined the Forest Service in early 1969 and his first position was as an Acquisition Inspector in Galway where he worked with Jim Kearney and Tim O'Connell. After four years, Sean was transferred to Bray where he worked as Assistant District Inspector and later on as District Inspector in Wicklow. Coillte was formed in 1989 and Sean's last position before his retirement from Coillte was as Environment and Landscape Design Manager for the Eastern Region. He achieved great satisfaction in this role, which was close to his heart and the expertise he had developed from his pursuit of photography was particularly helpful in this role. Sean retired from Coillte in 2002, but continued to work part-time on a consultancy basis for another four years.

Sean had many interests outside of his career in Forestry. His love of gardening and nature gained expression in the spectacular garden he designed and maintained at his home in Delgany. He was a great hurling fan and followed the fortunes of his native Limerick every year – mostly to no avail – although 1973 was a good year for him! He was a key member of his school's Harty Cup winning team in 1963. He was also a keen race-goer and unlike most punters he always appeared to make a profit from his investments.

Sean loved golf and was a member of Greystones Golf Club where he played on Wednesdays in a fourball which he never failed to miss. Sean was a good golfer even though he'd agree his swing was a little "agricultural" at times. My best memory of Sean was when he was playing a fourball with Dermot O'Brien against Declan Egan and myself in Santana Golf Club in Spain. It was all level going up the 18th when Sean disturbed a nesting black swan. Sean dived into the buggy and drove away with the swan in full flight behind him – needless to say, he and Dermot lost the match.

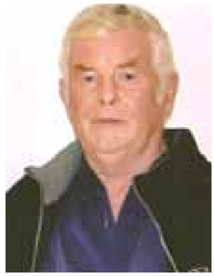
Sean's real love in life was his wife, Mary, and their daughters Hilary, Karen and Valerie. He was very much a family man and his newest passions were his grandchildren, Tomos, Eva and Fergal.

Sean had a great sense of humour and an innate wit, always pleasant and helpful to all his friends and colleagues. He is sadly missed.

We would like to express our deepest sympathy to his wife, Mary, daughters, Hilary, Karen and Valerie, his brothers and sisters, his extended family and friends on their loss.

Eddie Quinn

Kevin Mc Donald
1942 - 2011



Kevin Mc Donald passed away peacefully on the 4th Dec 2011 after a short illness which he bore with his characteristic courage. Kevin was born on the 26th March 1942 in the townland of Tomrud near picturesque Glencar, Co. Leitrim, in the scenic hinterland of "Yeats Country" with the backdrop of Glencar Lake and Waterfall to the west, as mentioned in W.B. Yeats's poem "The Stolen Child". Kevin attended Glencar National School about a mile away through the fields and later he cycled the five miles to St. Joseph's Secondary School in Manorhamilton.

After completing his second level education he "joined the forestry" and entered the Forestry Training School in Kinnitty, Co. Offaly in November 1959 under Superintendent Tom Prior. He was the only Leitrim man in a class of 32. In 1960 he moved on to Shelton Abbey Forestry College near Arklow, Co. Wicklow for his final two years. He won Wicklow Junior (1961) and Intermediate Championship (1962) medals while a student at the College.

His first appointment as a forester was to Kilcar Forest, Co. Donegal in 1962, and later he served as forester in Kilworth Forest, Co. Cork and Rathnew Forest, Co. Wicklow. Kevin returned to Kilcar Forest as Forester in Charge in the early 1970's. In 1974, he transferred to take charge of Lough Key Forest which included the Forest Park. On the 14th July 1977, he returned to Donegal to take charge of Castlefin Forest, including the workshop which serviced and repaired chainsaws and machinery for the Donegal forests. Kevin excelled in this work due to his gifted mechanical brain and had hands to match when required.

Continuing the family's close association with forestry, Kevin's brother, Bernie and his uncle, Tom Mc Donald, worked in Lough Gill Forest. When Kevin retired in 1991, he immersed himself in his many interests and hobbies which included farming, Gaelic football and acting as general handyman for neighbours and friends.

Kevin's unquestionable enthusiasm for, and dedication to, Gaelic football was evident at his local club and with the Sligo Region forestry team. He was a fine footballer and won many medals with his local club Glencar and Glencar/ Manorhamilton, including a Senior championship medal in 1977. Kevin also served as Chairman and Selector with the club. He played on and helped to organise the Sligo regional team which won the Regional Championship in 1978 and 1979. Kevin was also a great Leitrim supporter.

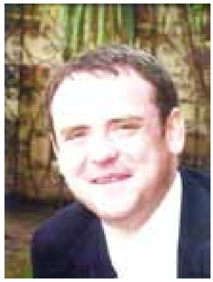
Kevin was a great supporter of the Society of Irish Foresters and was a regular participant in its Annual Study Tours. He had booked his place on the 2011 tour to Ontario, but sadly he was unable to travel.

Kevin was a quiet, unassuming man yet he was great company, thanks to his many hidden talents and extensive general knowledge. He was a kind, generous man, who quietly and unselfishly helped many people during his time in forestry and in retirement.

To his brothers Packie, Bernie, Tom, Leo, sister Mary, aunt Phyllis Kelly, uncle Tom Mc Donald, brother-in-law, sisters-in-law, nephews and nieces, we extend our deepest sympathy.

Thady Mc Ternan

Kevin Doherty
1977 - 2012



The world of Irish forestry was shocked when news broke of the untimely death, on 29th January, of Kevin Doherty. Kevin at thirty-four years of age had barely begun his forestry career when he was suddenly taken from us.

A native of Navan, Co. Meath but with deep roots in Co. Leitrim, Kevin began his forestry studies in 1995 completing a two-year Certificate in Forestry at Teagasc Ballyhaise Agricultural College, Co. Cavan.

In 1997, a number of that class went on to further forestry studies at the University of Central Lancashire, Newton Rigg Campus. At Newton Rigg Kevin and I, plus three of our Ballyhaise classmates, studied for their Higher National Diploma in Forestry (HND) before completing a BSc in 2001.

Kevin also spent a year working as a harvesting manager in England, Scotland and Sweden for Iggesund Forestry; this was during the second year of his HND course. When qualified, he began his forestry career with Greenbelt working with the company for five years. He then moved to Forestry 2000 in Kilkenny before ultimately, setting up his own company, Growwood Forestry Limited, in Kilclare, Carrick-on-Shannon, Co. Leitrim.

Kevin had a keen interest in forestry and he loved walking with his dog through the woods and countryside. He was a good talker and he convinced many farmers about the merits of investing in forestry. He continued to educate himself on new technology and new issues in forestry. Kevin was an active member of the Society and was an enthusiastic member of the Forestry Consultant's Group – Association of Irish Forestry Consultants (AIFC).

Kevin was very happy in Leitrim and he hoped to continue working with landowners in the area in developing and expanding his forestry business.

We offer our sincere sympathy to his parents, Seán and Kathleen, his brothers Philip and Shane, his sister-in-law Diane, his godson Aaron and his girlfriend Natalie.

Go ndéanfaidh Dia trócaire air.

Shane Mc Nulty

Denis Hayes
1915 - 2012

The second eldest of four children of Bartholomew and Kate, Denis Hayes was born in Glandore, Co. Cork on 22nd October 1915. His mother died when he was only 12 years old, but his was a happy childhood. He enjoyed the affection of his aunt and relatives as he helped out in the family farm and the pub/grocery shop in the village of Glandore. Denis went to the local national school before boarding in Rochestown College and Ballyfin College, Co. Laois where he completed his Leaving Certificate in 1934.

There was some family opposition to his announcement that he was opting for a career in forestry especially as he had already secured a teaching post at a private secondary school in Dunmanway. They relented however and after successfully completing the written and oral forestry exams, he entered Avondale Forestry School on 5th February, 1936.

His supervisor Danny McGlynn – who had also left a teaching post – advised him to reconsider his decision. He tendered his resignation but his fellow students convinced him to stay, which he did, and so began a career that lasted 44 years.

The training in Avondale was tough and covered a range of operations including nursery work, planting, pruning and harvesting before he was transferred on work experience to the fledgling forests of Aughrim, the Glen of Imaal, Cootehill and Cappoquin Forest.

Back to Avondale for his final year he received lectures from Alistair Grant. He also recounts visits to Avondale by two directors of forestry in Ireland during this period – the Scottish forester Mark Louden Anderson and Otto Reinhard a former Oberforstmeister in the Prussian Forest Service.

After successfully completing the course in Avondale he began his life as a forester in Athlone in July 1939 and within a year he was transferred to Ballinasloe. For the next few years, he involved in felling and extracting firewood during World War II. He fell into ill health for a time and often praised Anderson who recommended a period in a forest close to good hospitals. As a result he was transferred to Donadea in September 1946. By now he had settled down to married life with Kathleen (nee Marsh) whom he met in Athlone and married in 1943.

In November 1951, he was transferred to Durrow, Co Laois where he lived with his young family in an isolated dilapidated house deep in the forest. During this time he became acutely aware of the poor living accommodation and subsistence wages paid to foresters. Angered by the negative responses of the Department to submissions made on behalf of foresters in relation to pay, living accommodation and transfers he became actively involved in the then State Foresters Association (SFA).

The work of the SFA began to bear fruit during the 1950s when foresters were eventually granted Established status. The breakthrough finally came when the Department of Lands (Establishment of Foresters) Bill, 1952 was finally enacted in May 1953.

This meant that foresters were established Civil Servants which ensured that we had full pensionability and that their families would be cared for in the event of death or injury. He recalled in later years: "It is difficult to imagine it now, but achieving Established status made a huge difference to the morale and financial standing of foresters, in addition to granting a new-found status to our profession."

In 1961, Denis was appointed Assistant District Inspector in Kilkenny. He moved house for the last time to Kilkenny with his family. His final appointment as District Inspector (DI) in Kilkenny was a role he thoroughly enjoyed.

In this position he was a farsighted forester and enjoyed tremendous loyalty of foresters in his district. He was a founding member of the Society of Irish Foresters and encouraged debate and dialogue on all forestry issues. He was a strong proponent of commercial forestry but the wide range of soil types in Kilkenny provided opportunities to practice multipurpose forestry and species diversity.

Denis retired in 1980 but continued his interest in forestry. Up to a year of his passing, he wrote letters to the press opposing the privatisation of Coillte forests. He outlined the many benefits of State forestry and said in one letter that it "would be inconceivable to contemplate that any government would consider selling such a valuable asset for short-term financial gain". He understood well the hardship and struggle to create this rich resource, which he played such a major role in establishing.

Predeceased by his wife Kathleen, he is survived by Catriona and Declan to whom we offer our deepest sympathy.

Donal Magner

Letters to the Editor

6, Iris Grove,
Mount Merrion,
Co. Dublin.

The Editor, *Irish Forestry*

Re. Memories of Coole

Dear Editor,

Recently, when my cousin, Michael Carey, handed me a copy of the Journal of the Society of Irish Foresters (Vol 68 No's 1 and 2, 2011) and said I might read part of it I wondered. However, I must say Niall OCarroll's extract from Lady Gregory's Journal greatly interested me.

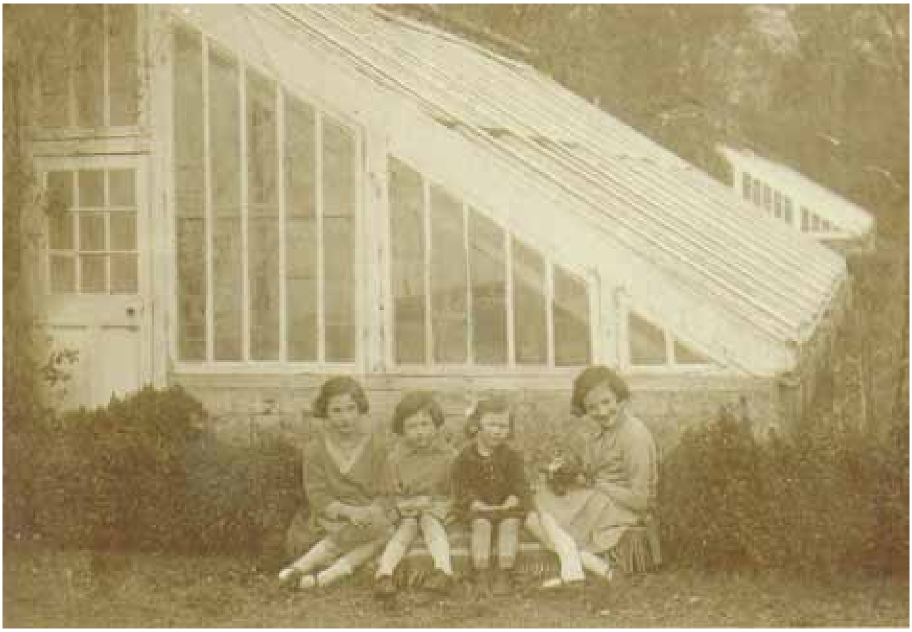
My father, Michael O'Beirne, was the State Forester in Gort from 1927-1940.[1] As a child of about six or seven years of age, I visited Coole on several occasions. I remember my mother having afternoon tea with Lady Gregory. They sat underneath a fig tree at the hall door for this. My sister and I were given wooden hoops to roll on the gravel in the front. We also enjoyed a Christmas party in a large room upstairs- a drawing room- with windows facing the lake. It was visible from the house at that time, as the trees had not taken over.

I love Coole, it's full of memories. I visit there at least once a year now. Sadly the Catalpa tree at the entrance to the flower garden is gone, as are the green houses, a wonderful herbaceous boarder on the left and of course the house itself. The autograph tree remains. I still enjoy walking through the seven woods as did my Dad and later my husband. It was certainly an experience to meet with such a famous lady, even if I was too young to realise so at the time. Thank you for rekindling those memories.

Regards,

Theresa Meagher (O'Beirne)

[1] Michael O'Beirne graduated in forestry from the Royal College of Science in Dublin. After his time at Gort he went on to become Superintendent of the Forestry Training School at Avondale. He was a founder member and a President of the Society of Irish Foresters. He retired in 1949 and died in 1951.



Photograph: *Sisters Sheila, Bea, Ann and Theresa O'Beirne (left to right, respectively) in the garden outside the conservatory at Coole Park on 16th April 1933.*

Doneraile,
Co. Cork.

The Editor, *Irish Forestry*

Re. International Fellowship at the World Forest Institute in Portland, Oregon

Sir,

I am writing to inform *Irish Forestry* readers of what I believe is an excellent opportunity for Irish forestry professionals to learn about forestry and forest practices in North America. I recently completed (Summer 2012) an International Fellowship at the World Forest Institute (WFI) in Portland, Oregon (http://www.wfi.worldforestry.org/). Below, I have outlined details of the program and briefly share experiences from my International Fellowship.

WFI is a non-profit organisation established under the aegis of the World Forestry Centre in Portland. The Institute has hosted more than 100 forestry professionals as International Fellows from over 80 countries since its inception in 1989. During my own short fellowship, I had the privilege of working with Fellows from Bolivia, China, Ghana, Iran, South Korea, Taiwan and Zimbabwe. WFI allows forestry professionals from around the world to conduct a short term (6-12 month) research project while also gaining valuable knowledge and insight from studying the forest industry in the Pacific Northwest (PNW) region of North America. Fellows typically split their time between (i) their research project and (ii) group activities.

(i) Research projects normally utilise WFI's strategic position in the heart of the PNW through a comparative research project — often using information from the fellow's home country and comparing with information from North America. The time allocated to the fellow's research project is normally ~70%.

(ii) Group activities are varied, but always focus on issues in the forest industry in North America. They include, but are not limited to, informing the public about forestry in the Fellow's country through public presentations, and learning about forestry in the PNW through varied site visits to forests, mills, university seminars and other locations. The group activities normally constitute 30% of the Fellow's time.

To qualify for a fellowship, researchers must design a suitable research project in collaboration with WFI personnel and secure half of the fellowship costs. A six month fellowship costs approximately \$10,000 while a 12 month fellowship costs approximately \$20,000. Once the Fellow has secured half of the fellowship costs, a matching grant from the Harry A. Merlo foundation provides funding to cover the remaining half of the program cost. My own fellowship was part funded by the Council for Forest Research and Development (COFORD) through a Networking and Knowledge Transfer Support Initiative grant. The fees for the fellowship are used to provide Fellows with a monthly salary, office space, cover the costs of site and conference visits, and visa fees. To my mind, the fees are a very minor investment, as the information, knowledge and contacts fellows acquire are of immense value.

My own research project investigated the macrofungal communities of Sitka spruce forests in its native (PNW) and non-native range (Ireland and Britain). Irish Forestry readers may be familiar with some of my previous work in 2011, examining the macrofungal biodiversity of Irish Sitka spruce forests (*Irish Forestry* 68, 40-53). For me, getting data from Sitka spruce in its native habitat and comparing it with that of its non-native habitat was the next logical step in elucidating patterns of the fungal biodiversity of Sitka spruce forests. Using WFI as my base, I acquired data from Sitka spruce forests on Vancouver Island, in Oregon and Washington, and even from the Queen Charlotte Islands (one of the few areas where Sitka spruce forms relatively pure stands) from several researchers located in the PNW. Along with these data, I also availed of numerous opportunities to meet with many important players in the fungal ecology world. My findings concluded that Sitka spruce supports as much fungal biodiversity as any other tree species investigated in each of my regions, thus indicting that it may be suitable as a conservation tool for fungal biodiversity in Ireland and Britain. I also found that the fungal communities in each region were clearly different, probably related to fungal biogeography patterns. Overall, this research is intended for publication in a peer-review conservation journal in the near future.

In addition to my research project, I also gained a lot from the group activities. We visited some of the large and small lumber mills along the PNW coast, including Sierra Pacific Co. and The Humboldt Redwood Co. We attended conferences on aerial photography, forestry education, urban forestry and watershed protection to name but a few. We also had the pleasure of visiting three National Parks, the temperate rainforest of the Olympic National Park in Washington, the volcanic forests of Lassen National Park, and the towering redwoods of the Redwoods National Park in California. These field trips were certainly the "cherry on top" for my International Fellowship.

Anyone interested in the prospect of securing an International Fellowship should first view the website (http://www.wfi.worldforestry.org/) or contact the program manager Chandalin Bennett (cbennett@worldforestry.org) to discuss the prospect. I can whole-heartedly recommend the International Fellowship program to anyone involved in forestry in Ireland, be they active foresters, forest mill employees, forestry researchers, or forestry academics including postgraduate students. Currently four non-native tree species make up the vast bulk of Irish forests, and two of these (Sitka spruce, lodgepole pine) come from the PNW. The International fellowship program gives Irish forestry professionals a chance to compare information about these species in their native and non-native habitats.

Best regards,

Richard O'Hanlon.

www.rohanlon.org