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The Society of Irish Foresters

Comann Foraoiseorí na nEireann

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

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

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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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Front cover: *Aerial view looking northwards over the JFK Arboretum, Co. Wexford. Image: Con Brogan, OPW.*

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EDITORIAL

Future of forestry in Ireland -unlikely to be a walk in the park

This year has been a momentous year for forestry in Ireland. We celebrated the centenary since the Faculty of Forestry was established at UCD (then the Royal College of Science), where Augustine Henry became the first Professor of Forestry. It is also 100 years since the publication of the "The Trees of Great Britain and Ireland", by Henry John Elwes and Augustine Henry (see Trees, Woods and Literature section). Other developments are also worthy of mention.

It is 50 years since John F. Kennedy visited Ireland (June) and his assassination (22nd November). The John F. Kennedy Arboretum in Co. Wexford is also 45 years-old (see also Forest Perspectives Section and the cover of this issue, which features a stunning aerial photograph). The Arboretum has an extensive collection of forest tree species from around the world, an invaluable repository of the types of trees that grow in Ireland. The Arboretum also contains valuable data on tree growth. With the fear of climate change looming, it is important to be able to evaluate the potential of different species to not only survive the predicted rise in temperature and reduced moisture availability, but also to continue to be productive. The future of the Arboretum has been uncertain for some time, so the Society has lobbied hard to secure its position. There has been a positive outcome in that regard, which the Society may have helped achieve. The National Botanic Gardens will take charge of the Arboretum and the title "JFK Arboretum" has been retained, which is welcomed. However, it is not clear as to whether or not a long-term plan for the development of the Arboretum has been put in place, which is worrying. Sadly there is also a link with an obituary in this issue, the death of Dr Jack Durand. Jack was Director of the Arboretum from 1972 until 1978 and contributed greatly to its development during those years.

Many readers will have welcomed the news that the Irish government will not sell Coillte's harvesting rights. The Society campaigned to protect the public ownership of Irish forests, publishing a policy document on the subject in 2013. The Society believes that privatisation had the potential to disrupt the sustainable development of forestry in Ireland. However, it is not clear if Coillte is out of the woods yet. It remains to be seen if the proposed merger between Coillte and Bord na Móna goes ahead, and in the meantime, the continued uncertainty about the future of the company is not good for Irish forestry. In particular, there is concern that the Coillte part of this planned new entity might shift its focus away from the multifunctional value of forestry into other areas such as energy production.

The potential threat of disease and/or pest damage to Irish forests is real, a threat that has perhaps been exacerbated by a changing climate. The journal commissioned a paper by Dr Alistair McCracken on this topic, entitled "Current and emerging threats to Ireland's trees from diseases and pests", which is likely to be of huge interest to our readers. We are indebted to Dr McCracken for carrying out this detailed review. Dr McCracken also presented an excellent talk on this topic at the Annual Augustine Henry Forestry Lecture, held at the Botanic Gardens in Dublin in March entitled “Are Ireland’s Trees Under Threat from Pests and Diseases?”

Dr McCracken’s paper is particularly timely given the reported spread of the ash dieback disease (*Chalara fraxinea*), found in recent times on nursery, garden centre, and roadside plantings. The majority of the outbreaks have been identified as part of a trace-forward exercise of batches of plants originating from a source known to be infected. Almost all of the trees were planted within the past five years, but there has been a recent report that the disease has been found on native hedgerow material.

In relation to ash dieback, Dr McCracken suggests that it may be possible to breed for resistance, but this is not likely to be an easy or inexpensive task. In one Danish study[1], only a small fraction of the ash trees were found to possess resistance, so it may not be possible to exploit this resistance without the risk of other adverse consequences. Some of the resistance may be indirect, perhaps reflecting the ability of some trees to “avoid” damage. In general, the most susceptible trees in that study were those whose buds flushed latest and retained their leaves latest into the autumn. It may be difficult to justify investing in a disease resistance breeding programme at the national level, but collaborating with other European countries on breeding efforts to this end may make more sense.

Plant health strategies and policies at international, national and local levels need to be developed to address ash dieback and other disease and pest threats. In particular, the lack of expertise (mainly as a result of retirements) and low level of research investment in the area of tree health are of concern. There is currently no forest pathologist working in Ireland. Given the limited resources available to it and other limitations, the Forest Service is doing a decent job in trying to address these problems. Nevertheless, the current approach is mostly reactive and appears to rely heavily on information supplied by well-meaning amateurs. The lack of expert advice has led to poor decision making. The Department of Agriculture is urged to act now in the interest of forest health.

[1] McKinney, L.V. Nielsen, L.R. Hansen, J.K. and Kjær, E.D. 2011. Presence of natural genetic resistance in *Fraxinus excelsior* (Oleraceae) to *Chalara fraxinea* (Ascomycota): an emerging infectious disease. *Heredity* 106: 788–797.

A comparison of two yield forecasting methods used in Ireland

Andrew McCullagh[a]*, Michael Hawkins[a], Lance Broad[b] and Maarten Nieuwenhuis[a]

Abstract
A comparison was made between two methods for forecasting the growth and yield of five conifer species growing in even-aged stands in Ireland: the Forestry Commission (FC) Yield Tables and the dynamic yield modelling system Growfor (GF). The goal of the study was to examine and compare the outputs of each system as both are used in forest management planning and decision making in Ireland. A typical regime used in the FC yield tables was adopted and the details of this regime were used as inputs into GF. The cumulative volume was examined under a no-thin scenario and also under a scenario that involved thinning to the marginal thinning intensity (MTI). Using the GF system, volumes were significantly lower than with the FC system, for both the no-thin and the thinning scenarios, for most species. In the no-thin scenario, Norway spruce, lodgepole pine and Douglas fir showed deviations from the FC trend while Sitka spruce and Scots pine showed similar patterns to the FC volumes. Under the thinning scenario, Sitka spruce showed a similar trend to the FC volume while the GF volumes for the other species deviated from the FC ones. The MTI proved too severe and resulted in a loss in the productive capacity of the stands. Cumulative volume production was increased by reducing the thinning intensity.

Keywords: *Growfor, dynamic model, yield table, forecast, growth.*

Introduction

Yield models provide information on the future yields and assortments of stands. This information is necessary in forest management in order to make decisions on the profitability of afforestation, rotation length, thinning operations and harvests. With accurate projections of future outputs, the forester is well placed to make important management decisions to ensure optimal timber volume and value production.

The history of growth and yield modelling in even-aged plantation silviculture in Europe dates back to over 200 years ago. From the late 1700s onward, yield tables were being constructed by several German scientists such as Hartig, von Cotta and Heyer, cited in (Pretzsch et al. 2008). A yield table is a summary of the expected yields tabulated by inventory variables (Skovsgaard and Vanclay 2008). As these tables were based on estimates and limited observational data, they were known as "experience tables". Gaps in knowledge were noticed as a result of these

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and long-term experimental plots were set up, which are still maintained to the present day (Pretzsch et al. 2008).

Theoretical principles and biometric equations began to be developed. Heyer was the first to identify a correlation between height and volume in the middle of the 19th century (Skovsgaard and Vanclay 2008). In 1904, Eichhorn discovered that the standing volume production of European silver fir (*Abies alba* Mill.) is a function of stand height within limits of stand density and thinning treatment. This was confirmed for more species and then extended so that total volume production was also a function of stand height by Ernst Gerhardt in 1921, cited in (Skovsgaard and Vanclay 2008).

The Forestry Commission (FC) yield tables are based on Eichhorn's rule. A "master table" was produced by Hummel and Christie (1953) in which top height was related to the other stand characteristics: stems per ha, mean diameter, basal area and volume per ha. The models are based on yield class, which is defined as the maximum mean annual increment (MMAI) of a stand, and is measured in volume per ha per annum (Johnston and Bradley 1963). Yield class was used as an index of stand productivity but since volume is difficult to measure, top height and age were used and these were then related to volume. Growth curves were produced for each species which allowed the determination of yield class from the height and age of the stand in question. Baur was the first to include height as a site classification in a yield table in 1877, cited in (Skovsgaard and Vanclay 2008).

For the last thirty years, foresters in Ireland have made use of Yield Models for Forest Management (Edwards and Christie 1981). This publication replaced Forest Management Tables (metric) (Hamilton and Christie 1971), which only included normal stocked plots and did not include unthinned models. Both sets of models are based on the same datasets but there is a wider variety of spacing regimes in the 1981 tables. The yield tables were derived from a set of curves which described how pure even-aged stands grow and develop over time for different species. The marginal thinning intensity (MTI) is 70% of the MMAI and it is assumed that this is the maximum amount that can be extracted annually from the stand without causing a loss of volume production (Edwards and Christie 1981). The regimes consist of a variety of initial spacings and thinning treatments. The yield models assist the forester in making decisions on when and how heavily to thin, and when to harvest. These are known as static models as it is necessary for the forester to follow the regime as deviations from the prescribed regime reduce the reliability of the forecasts. This reduces the number of options available to the forester as the management approach must be matched to the model. Notwithstanding this limitation and the fact that the models were developed in Great Britain and are based on British data, they have served Irish forestry well.

Development of a dynamical system to represent forest growth in Ireland was undertaken by Broad and Lynch (2006a). The system is based on the state-space approach as developed by García (1984). With sufficient information on the state of the system it is possible to forecast future states. The state vector and the transition function contain the necessary information required to make a forecast. The growth equation used in the system is the Bertalanffy-Richards equation (1957):

$$\frac{dx^c}{dt} = ax^c + b \tag{1}$$

where a,b,c are parameters. It is widely used on account of its flexibility and the biological basis on which its parameters rest (Zeide 1993).

In Equation 2, the state vector x consists of the basal area (B), stocking (N) and height (H):

$$\mathbf{x} = (B, N, H)' \tag{2}$$

where x is a vector. The growth equation is extended to a multivariate version using a power transform in which the state vector is raised to a matrix power:

$$\mathbf{x} \equiv \exp\,(\mathbf{C} \ln \mathbf{x}) \tag{3}$$

where C denotes a 3×3 matrix. Expanding to a multivariate system:

$$\frac{d\mathbf{x}^{\mathbf{C}}}{\mathrm{dt}} = \mathbf{A}\mathbf{x}^{\mathbf{C}} + \mathbf{b} \tag{4}$$

where b is a vector, A denotes a 3×3 matrix, allows for a system of differential equations to be used to represent forest growth. There is a sub-model to evaluate the height parameters (García 1983). Top height at a reference age (30 growing seasons since planting) is used as a measure of site productivity (also known as "site index"). Both polymorphic and anamorphic representations are possible but the polymorphic form proved to be a better fitting model in the Irish context (Broad and Lynch 2006a). The thinning function consists of a differential equation for the change in basal area against the change in stocking, which describes the change in the state of the system after a thinning. The form of the volume equation is determined using a stepwise regression. A predictor set is defined in the process and includes the following: H/√N, N.H/B, 1/H, B/H, 100/(B.H), S/B, S.S/B. Using the thinning function with the volume function produces the option to thin by volume as per the yield table approach. The only information necessary to calculate forecasts and assortments is a time slice of stand data: age, stocking, top height and basal area or DBH; importantly, details of previous silvicultural operations are not required as in the FC methodology. This results in added flexibility in that the forester is not constrained by a fixed regime such as in the yield tables. The models are contained in a graphic user-interface in the program "Growfor" (GF) which allows adjustment of thinning times and intervals as well as thinning intensity. As the models were fitted in Ireland and are based on Irish data, the expectation is that they should produce more accurate forecasts.

In an earlier study by Broad and Lynch (2006b) an assessment of the suitability of SS research data for growth modelling was undertaken. Three possible sources of bias were identified including a sampling bias that omited lower site index material, a subjective selection of larger volume sample trees, and experiment blocking which reduced randomisation. The authors argued that the volume sampling bias led to the over-estimation of volume production in plots. The authors believed this bias was present for all species in the Coillte database. Work was undertaken to mitigate this bias using independent data where possible.

The objective of the study is to compare the cumulative volume from both forecasting systems. Typical regimes from the yield tables for each species make up the input to the dynamic system and the outputs from both systems are analysed graphically and using the Mann-Whitney-Wilcoxon test.

Materials and methods

The tree species used in the study are the main timber species in Ireland, including Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Norway spruce (*P. abies* (L.) Karsten), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), Scots pine (*Pinus sylvestris* L.) and lodgepole pine (*P. contorta* Dougl.), hereinafter respectively known as SS, NS, DF, SP and LP. Details of the development of the SS model are available in (Broad and Lynch 2006a); the same approach as used for SS was adopted for each of the species listed above. However, there is one difference in the approaches. After a period of model testing it was discovered that the volumes in the SS model were lacking an asymptote and thus required further attention to fix the upper growth limits. The models were validated using data independent of the development data.

A typical regime from the 1981 FC yield tables was used to compare the outputs from each system. This regime was one defined by the top line of each of the tables. The spacing was 2 by 2 m, a 5-year thinning schedule was adopted and an intermediate thinning was used. For each species the highest yield class (in brackets) was used: NS (22), SP (14), SS (24), LP (14) and DF (24). The regime differed for DF: 1.7 by 1.7 m spacing was used since a 2 by 2 m table was not available while a crown thinning was adopted as vigorous dominant trees with coarse branching (i.e. wolves) are common among DF trees. The rotation length was defined as the age when the mean annual increment reached a maximum. A revised set of yield tables that was developed for LP in 1975 based on data from thinned stands grown in Ireland (Phillips and O'Brien 1975) was also used.

The first line of the yield tables contains information on the age, top height, stocking and basal area, figures that are also the input to GF model. Thinnings are controlled by volume reduction and the management goal is that of maximising volume production. The output in GF follows the format of the yield tables. The data for the study consists of the outputs for the GF and FC models. This allows for direct graphical comparisons.

For each species the following scenarios were examined:

- No-thin treatment.
- MTI was used, which is 70% of the MMAI as per the yield tables.
- The effect on the cumulative volume was examined when reducing the thinning intensity by 7%, 14% and 21% from MTI.

The data were also compared with a nonparametric test, the Mann-Whitney-Wilcoxon test using the Wilcox function in the R stats library, R version 2.13.1 (R Development Core Team 2012). Separate comparisons were made for no-thin and thinned data. The model outputs for the five species constituted the samples to be compared in each case, i.e. $n_1 = n_2 = 5$.

Results

A series of graphs was produced for each species depicting cumulative volume against age for both systems which allowed comparisons of the volumes produced in the two modelling systems (Figures 1 and 2).

No-thin scenarios

For four of the species in the no-thin scenarios, the GF model produced lower cumulative volumes than the FC tables (Table 1, Figure 1). The SS volumes were similar under both models: 1,026 $m^3 ha^{-1}$ under the FC table and 1,014 $m^3 ha^{-1}$ under the GF model. The difference between the FC and GF values for SP was greater than that for SS but smaller than those of the other species (Figure 1). The

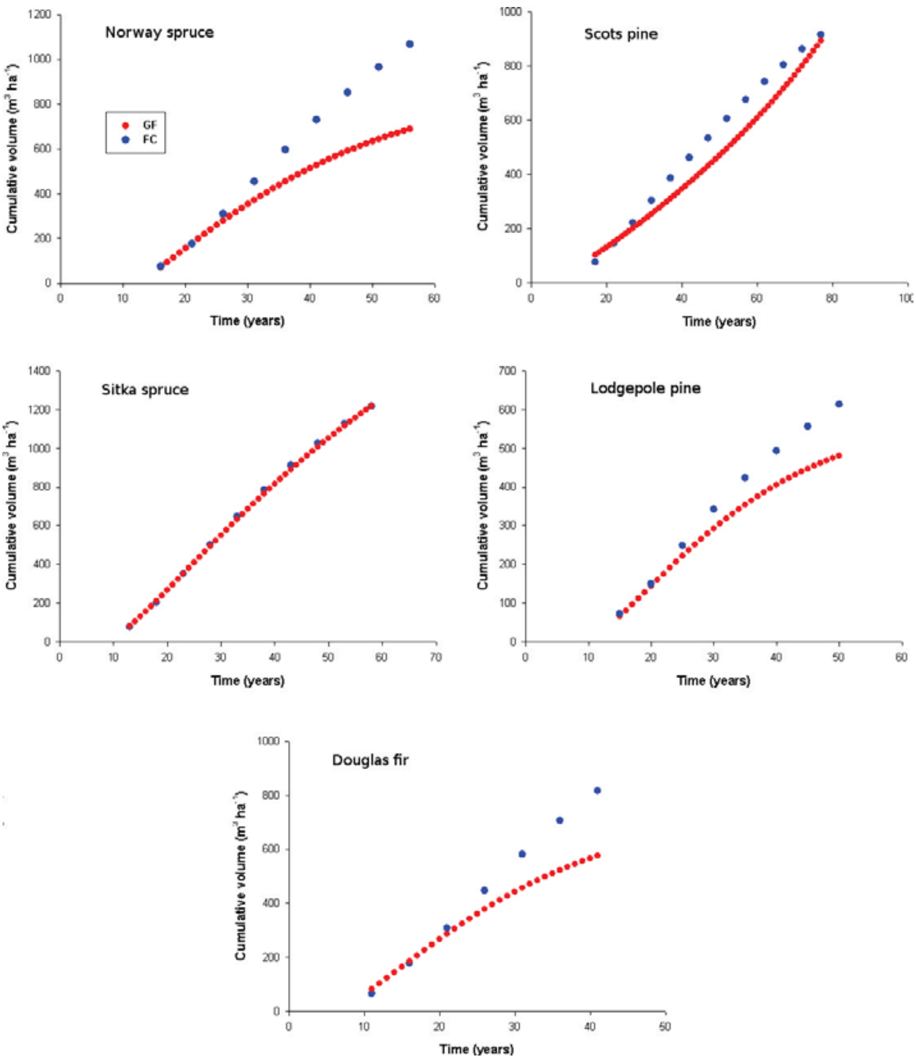

Figure 1: *Graphs of cumulative volume against time of each species under a no-thin scenario. GF = Growfor, FC = Forestry Commission yield tables.*

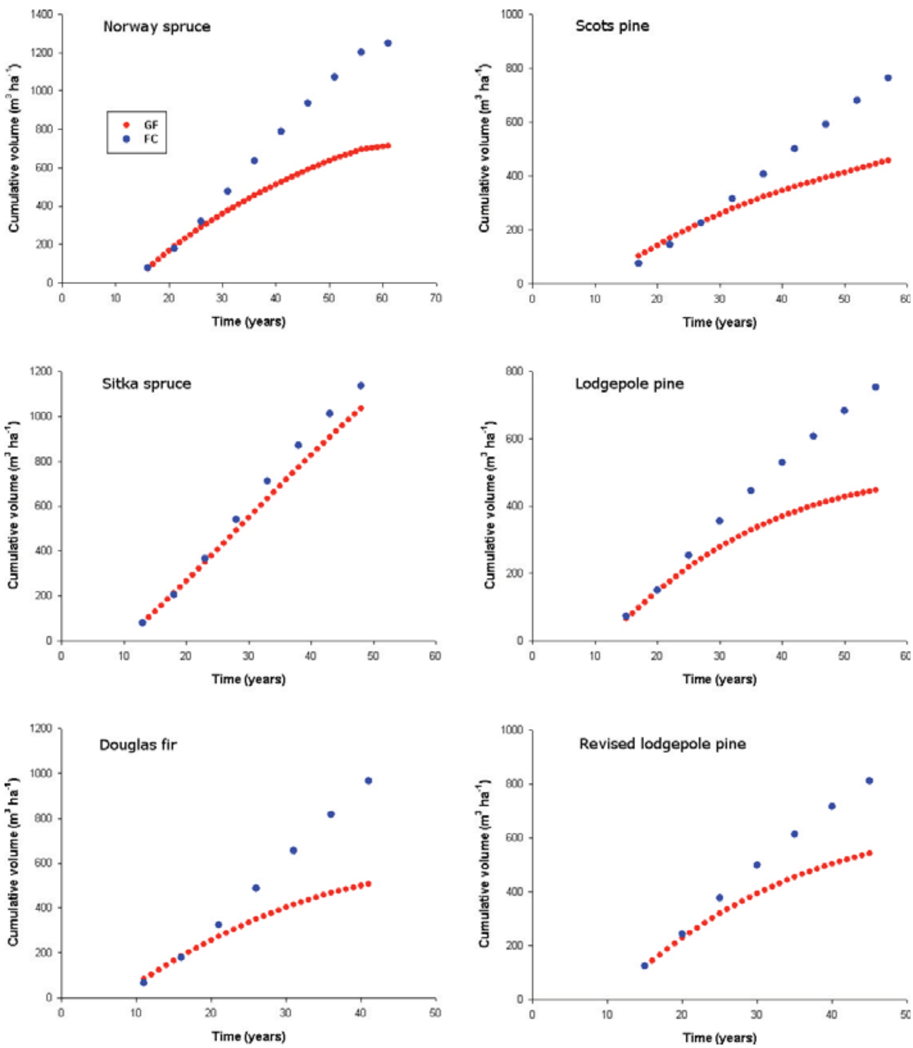

Figure 2: *Graphs of cumulative volume against time of each species under the MTI scenario. GF = Growfor, FC = Forestry Commission yield tables.*

Table 1: *Predictions of cumulative volume (m^3 ha^{-1}) production over the rotation of MMAI of each chosen species by model for the no-thin scenario; FC = Forestry Commission yield tables, GF = Growfor models.*

	Norway spruce	Scots pine	Sitka spruce	Lodgepole pine	Douglas fir
FC	1069	742	1026	613	816
Rotation (yrs)	56	62	48	40	41
GF	690	637	1007	480	576

median latencies in the groups FC and GF were 816 and 637 m³ ha⁻¹ respectively; the distributions in the two groups differed significantly (Mann–Whitney $U = 20$, $n_1 = n_2 = 5$, $P < 0.05$ one-tailed).

Thin scenarios

When thinning to the MTI, the cumulative volume of each of the species was lower in GF than in FC (Table 2, Figure 2). The revised LP table also shared this trend. The volume produced for SS under the FC yield tables was 1,135 m^3 ha^{-1} and 995 m^3 ha^{-1} under GF (Table 2). The other species showed much greater differences. Median latencies in the groups FC and GF were 965 and 506 m^3 ha^{-1} respectively; the distributions in the two groups differed significantly (Mann–Whitney $U = 22$, $n_1 = n_2 = 5$, $P < 0.05$ one-tailed).

The volume that was being extracted when thinning to the MTI was too large since the main crop was becoming depleted and the bulk of the cumulative volume was arising from the thinnings as opposed to the main crop (Figure 3).

Table 2: *Predictions of cumulative volume (m^3 ha^{-1}) production over the rotation of MMAI of each chosen species by model and the thinning intensity (FC 70 thinning at MTI (70% of MMAI); GF 70 thinning to MTI; GF 63 thinning to 63% of MMAI; etc.).*

	Norway spruce	Scots pine	Sitka spruce	Lodgepole pine	Revised lodgepole	Douglas fir
FC 70	1,318	840	1,135	752	810[a]	965
Rotation (yrs)	61	62	48	55	45	51
GF 70	714	500	995	447	541	506
GF 63	794	554	1,029	472	555	611
GF56	829	623	1,050	494	566	656
GF 49	854	624	1,064	514	578	681

[a] Value equates to MTI in the revised lodgepole table.

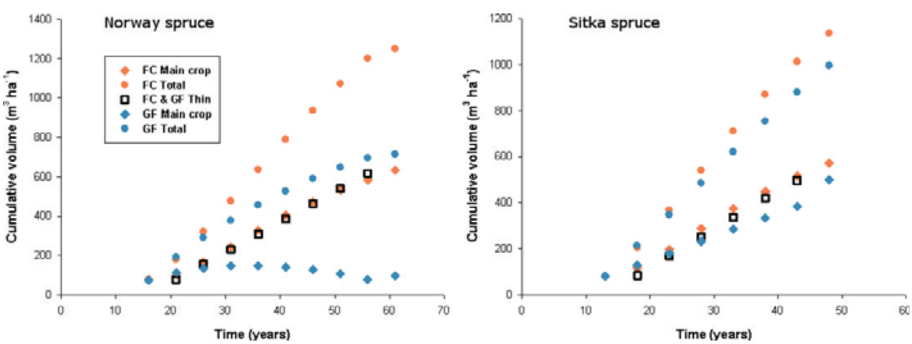

Figure 3: *Graphs of the main crop, the thinning and total volume for Norway spruce and Sitka spruce under both modelling systems FC = Forestry Commission yield tables, GF = Growfor.*

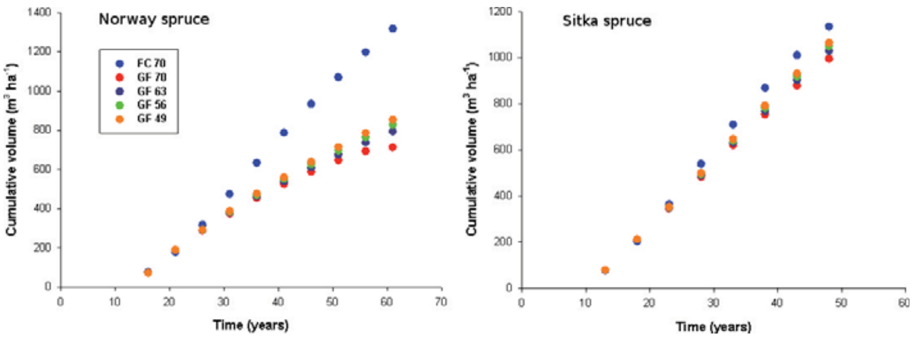

Figure 4: *Graphs of volume against time under varying thinning intensities for Norway spruce and Sitka spruce under both modelling systems. FC 70 thinning at MTI (70% of MMAI); GF 70 thinning to MTI; GF 63 thinning to 63% of MMAI; etc; FC = Forestry Commission yield tables, GF = Growfor.*

Thinning intensity reductions

For each of the species, the cumulative volume production was progressively increased by reducing the thinning intensity by 7%, 14% and 21% of the MMAI. At the greatest reduction, cumulative volume production still remained much lower than using the MTI with the FC models. The trend is shown for NS but a similar pattern was produced for each of the other species with the exception of SS (Figure 4).

Discussion

The volume outputs for each modelling system are different as each system is based on a different approach. GF is based on the state-space approach and makes use of site index whereas FC uses yield class. The functions within each of the forecasting systems are different. In GF the volume and thinning values are evaluated as per the functions described in the Introduction. The FC volume values are derived from the master table and the thinning values are determined using the yield class and the desired thinning intensity once a stand becomes fully stocked. Mortality is treated differently too.

In the FC tables mortality is only considered up to the first thinning. Subsequent mortality is considered recoverable, whereas in GF mortality is recorded as it occurs (Broad and Lynch 2006a). A major factor is that the systems are not based on the same dataset. The climate in Ireland is not identical to that of Britain, but more importantly, the treatments in each country's respective research plots would not have been the same.

The fact that SS deviates from the main trend, that of GF forecasting volumes significantly lower than FC volumes, leads to the question – does SS in Ireland actually grow similarly to that in GB? A study in 1972 showed that the volume in unthinned Irish SS stands was greater than the figures displayed in the yield tables (Hamilton and Christie 1971) and that Irish stands could achieve yield class values greater than 24 m^3 ha^{-1} yr^{-1} (Gallagher 1972). Although the results of that study contradict our findings, it does highlight the fact that SS volumes are close to those in GB thereby explaining some of the deviation of SS from the trend. It is also possible is the greater quantity of older age data available that was available for SS than for the other species might cause this deviation. However theoretical equations such as the Bertalanffy-Richards growth equation are known to extrapolate well outside the range of development data (Vanclay 1994) which would suggest that extra data should not produce such a dramatic effect. An additional limitation associated with the development of the SP GF model was the availability of only a small dataset and caution is required when drawing conclusions based on its use.

Purser et al. (2004) discussed the possible impacts that climate change may have on Irish forestry. Rising CO_2 levels could stimulate forest growth, while increasing temperatures have the effect of speeding up chemical and biological processes in plants and could cause an increase in primary production. However, extreme events such as summer drought may reduce growth rates of common species (Broadmeadow and Ray 2005). Dynamic models are based on repeated measures of stand level data with the goal to forecast production values. Unlike ecosystem process-based models, there is no facility to model the effect of climate change. Re-parameterisation based on new data which is assumed to incorporate the effects of a changing environment under climate change is a feasible but impractical approach. Indeed the data used to produce the dynamic models includes the impact of climate change over the measurement periods. García et al. (2011) depicted a framework in which the state-space approach may be extended to simulate biomass, carbon and nutrient cycling in order to model the effects of climate change.

The FC tables extract thinning volumes which, when adopted in GF, generally resulted in too much volume being removed in the thinnings. The main crop that remains is not producing the maximum or even a sustainable, volume increment and damaging the stand's productivity potential. It is possible that the MTI is too high or that there are significant incompatibilities when thinning to the MTI under the GF system. Indeed, the views expressed by practitioners attending a recent COFORD seminar (COFORD 2011) support the view that there is awareness among Irish foresters that the FC thinning models overestimate the main crop volume increment. For this reason, several foresters indicated that, even though they use the FC models, they do not thin to MTI, especially at younger stand ages. Reducing the thinning intensity demonstrated that the cumulative volume production under GF could be increased and that more appropriate results are obtained when a lower intensity is adopted.

The main crop that remains after thinning to the MTI was small as the bulk of the cumulative volume was in the thinnings. There may be situations where this is planned, but usually this is not the management objective. The most valuable stems would be the largest ones that live for a full rotation, so it would be in the forester's interest to maximise the volume of the final harvest. In reality, most forests are managed in order to yield the greatest profit or rate of return and the development of a user-defined assortment component for GF, which is currently under way, will allow the user to analyse the financial return of different thinning and rotation choices. An optimisation routine, which determines the financial optimal thinning and rotation parameters, given user-specified assortments and timber prices, can then be developed using dynamic programming or network methodologies (Nieuwenhuis 1989). Currently, data included for model development has mainly included stands which have had low thinnings. However, should data from stands which have had crown thinnings become available, then specifying the material to be removed in a thinning would become a possibility. This feature would be of particular interest to foresters looking into alternative silvicultural practices.

The dynamic model GF is based on the site index system. Site index is the top height a stand is expected to have once it reaches the base age. It is used as an indication of site productivity; a higher site index indicates a more productive site. Unlike the use of yield class in the yield tables, site index is generally independent of management and is therefore a more general and robust site productivity indicator and is used worldwide. As these site index models are not based on the yield class system, it is to be expected that the concept of MTI does not really apply and a different method of defining the thinning intensity is required.

Recommendation

The results of this study support the view that Irish foresters should move away from the use of static yield tables. The lack of options available when adopting a prescription restricts the forester and prevents any investigation into alternative silvicultural practices. Since deviating from a prescribed regime reduces the reliability of the projections and, taking the differences highlighted above into consideration, it is recommended that the dynamic approach is adopted. GF has been developed using Irish stands and thus projections should be more accurate and relevant to the Irish forester. Moreover, the wide range of options with regard to thinning times and intensity provides a flexibility that is not available with the static approach.

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Forestry and a low carbon economy – a background paper

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Abstract
The forest sector plays and will play an important role in relation to climate change mitigation and the development of a green economy. Sequestration of carbon dioxide through forest cover expansion and management of forests, allied to the production of wood and wood products to replace fossil fuels and energy intensive materials, are the main contributions that the forest sector in Ireland makes to climate change mitigation. Significant potential exists to increase this contribution. Looking to the global scale, reduction and avoidance of deforestation is the key forest policy that will contribute to reduction in greenhouse gas emissions. However, there are a number of uncertainties and unknowns that need elucidation and clarification before the full potential of the forest sector can be determined and optimised. This article provides an overview of the current state of knowledge in relation to the forest sector's existing and potential contributions to the development of a green economy and follows this with a discussion of important issues that need clarification and research. It is essential to ensure that the contribution of the forest sector as an efficient carbon sink and as a producer of renewable, low-carbon materials does not adversely impact on forests as providers of a wide range of other ecosystem goods and services.

Keywords: *Green economy, renewable energy, low carbon materials, forest sector.*

Introduction

The forest sector plays and will play an important role in relation to climate change mitigation and the development of a green economy. Sequestration of carbon dioxide through forest cover expansion and management of forests, allied to the production of wood and wood products to replace fossil fuels and energy intensive materials, are the main contributions that the forest sector in Ireland makes to climate change mitigation. Significant potential exists to increase this contribution. This article provides an overview of the current state of knowledge in relation to the forest sector's existing and potential contributions to the development of a low carbon economy, and follows this with a discussion of important issues that need clarification and research.

The global picture

Next to peatlands, forests are the largest terrestrial store of carbon on the planet and their use and management play a significant role as drivers of climate change on the

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one hand, and in climate change mitigation and adaptation on the other. Recent estimates by Pan et al. (2011) suggest that the entire terrestrial carbon sink can be accounted for by the uptake by globally established forests, and consequently that non-forest ecosystems are collectively neither a major sink nor a major source. While these estimates are at a global scale and there are very significant regional divergences, they point to the strength of the forest sink, even after netting out emissions from deforestation.

Deforestation and subsequent land-use change, mainly in tropical regions, accounts for up to 18% of greenhouse gas emissions, about 5.8 billion tonnes of carbon dioxide (CO_2) equivalent per year, which is more than the total of global transport and aviation combined (IPCC 2007). Measures to address forest loss in tropical countries have been underway for many decades, through development aid and other means, but these have had limited impact. Since the Montreal United Nations Framework Convention on Climate Change conference in December 2005, discussion and negotiation has continued in the process of what has become known as REDD+: Reducing Emissions from Deforestation and Forest Degradation + conservation and management of carbon stocks. Some progress has been made, the Cancun agreement at the end of 2010 included measures to slow, halt, and reverse forest loss and the related emissions in developing countries. Before, and increasingly since Cancun, capacity building in the measurement, reporting and verification of forest carbon stocks and stock change has been underway in developing countries. One of the key issues that remain is how to provide a link between verified emission reductions and removals in REDD+ and compliance with greenhouse emission reduction targets in developed countries. There is little doubt that a successful REDD+ mechanism will need to be in place if the EU is to achieve emission reductions of the order of 80–95% on 1990 levels (the EC's *Roadmap for moving to a competitive low carbon economy in 2050*), notwithstanding the emphasis the roadmap places on domestic action in Member States. As for other Member States, REDD+ is of strategic interest for Ireland, especially having recently become more closely engaged through becoming a member of the European Forest Institute's (EFI) EU REDD facility, and providing funds for its activities.

Conceptual and accounting frameworks for land use, land use change and forestry

The Intergovernmental Panel on Climate Change Fourth Assessment Report (IPCCC 2007) provides a conceptual framework to consider the contribution of the forest sector to climate change mitigation. It can be summarised as sequestration, replacement and substitution:

- net sequestration or uptake of atmospheric carbon, through avoidance of deforestation, extending forest cover and enhancing carbon uptake in existing forests, and through related measures;
- replacement of fossil fuel by biomass from forests and other sources (provided the wood comes from sustainably managed forest and preferably from forests within the international accounting system); and
- materials substitution using wood products in construction and other end

uses, with the benefits of reduced emissions from manufacture and placing carbon in storage.

The role of the global forest sink in tackling climate change has been recognised from the outset by the United Nations Framework Convention on Climate Change (Article 4.2 of Convention). Following on from the Convention, the Kyoto Protocol provided the accounting framework for forest sinks. The most recent set of rules for land use, land-use change and forestry (LULUCF) for the post 2012 period were agreed in Durban at the end of 2011. In principle the rules will apply only to those parties that will commit to take on legally-binding emission reductions for the post-2013 period, though other developed country parties who have stated an unwillingness to take on commitments in the absence of global agreement to reduce emissions have indicated that they intend to apply the rules in meeting unilateral emission reduction pledges.

The Durban rules (FCCC/KP/CMP/2011/10/Add.1) were negotiated taking into account the IPCC guidance, and for those countries that will sign up to a second commitment period under Kyoto they will:

- extend the mandatory nature of forest carbon accounting to all managed forests, and, through the use of a reference level for forest management and the rules for afforestation, provide the basis for an incentive structure that rewards activity that will result in sequestration levels over and above business-as-usual;
- strengthen the environmental integrity of the use of forest-based biomass sourced within and from countries that sign-up to a second commitment period; and
- provide, for the first time, an accounting framework for harvested wood products that is based on actual service-life.

The new rules should help to level the playing field between the three different mitigation contributions and enable cost-effective mitigation strategies and technologies to emerge.

National and EU policies and measures

Forest sinks are part of the compliance regime for the first commitment period under the Kyoto Protocol, which runs from 2008 to the end of this year (2012). Forests will contribute substantially to Ireland's target: about 14 million tonnes of carbon dioxide, sequestered over the period 2008–2012, in new forests established since 31st December 1989. National projections made using the COFORD CARBWARE model (Black et al. 2012) indicate that this level will increase to 4.6 million tonnes of carbon dioxide per annum by 2020 (EPA 2012). It remains to be seen if and how this quantum of carbon will be included or recognised in target setting and compliance. In-so-far as activities such as afforestation are funded to address climate change mitigation, there is a logical link to target-setting and then compliance. Going further, the interchangeable nature of the carbon sink units within the Emission Trading Scheme (ETS) is a logical link in the context of enabling the most cost-effective mitigation systems and technologies to emerge over time, as long as issues such as reversibility and any consequent liability are addressed.

Inclusion of sequestration post 2012 will depend on the outcome of the discussion of the European Commission's LULUCF proposal. Also important are the international negotiations and the EU's emission reduction target, bearing in mind that the EU has said it would consider moving towards a 30% reduction by 2020 if certain conditions were fulfilled. The Commission's proposal, issued on the 12th March 2012, is for a decision on accounting rules and action plans on greenhouse gas emissions and removals resulting from activities related to land use, land-use change and forestry. The proposal states that "The main objective of this Decision is to establish robust and comprehensive accounting rules for LULUCF as well as to enable future policy development towards the full inclusion of LULUCF in the Union's greenhouse gas emission reduction commitments when the conditions are right." The proposal is currently under discussion between the Commission and the Member States.

The forest estate and its outputs

Forest cover in Ireland and in Europe

Forest cover in Ireland reached 731,650 ha in 2012, or nearly 10.5% of total land area. This compares to a European average of 43% (FOREST EUROPE, UNECE and FAO 2011). In Ireland, most new plantings were undertaken by the State up until the mid 1980s. However, the introduction of EU co-funded support programmes at that time was a catalyst for a significant increase in private afforestation.

The level of planting by the private sector exceeded public planting by the mid to late 1980s, with the latter virtually ceasing since 2001 (Figure 1). Private planting peaked around the mid 1990s and although levels had increased somewhat in recent years, in 2011 there was a 20% decrease to 6,653 ha in the area of grant-aided afforestation. (One of the factors at play in reducing the level of uptake seems to be uncertainty as to how the level of single farm premium payments will be calculated in the post 2013 period.) The proportion of privately-owned forest land has now reached 47% (end 2011). There has been a significant increase in broadleaf planting since 1996 reflecting the revised support structure for such plantings. Broadleaves accounted for nearly 37% of new planting in 2011, exceeding the 30% target.

Irish timber harvest and woodflow

In 2010, 2.88 million m^3 of roundwood was harvested in the Republic of Ireland[1]; 2.7 million m^3 of which was utilised by the processing sector (Table 1), with the balance of 199,000 m^3 being used for firewood. Private forest harvest grew by 356% over 2009 driven by strong demand across all assortment classes. Of the roundwood that was processed in the Republic of Ireland, 82% was supplied by Coillte with 17% provided by the private forest sector; the balance was supplied by imports.

[1] For further information on wood harvest and forest products trade see Woodflow and forest-based biomass energy use on the island of Ireland – COFORD Connects Note: Processing/Products No 27.

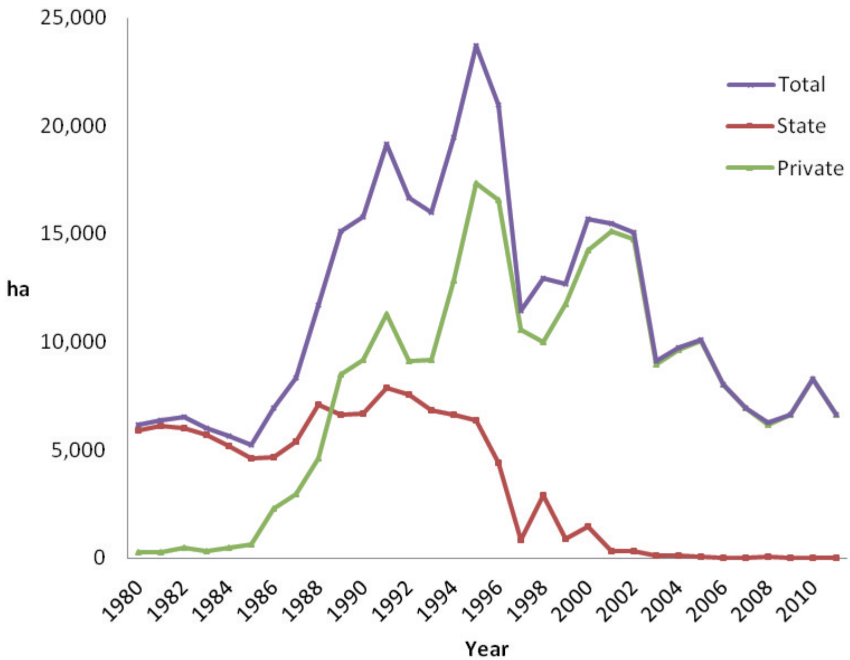

Figure 1: *Public, private and total afforestation from 1980 to 2011. Source: Forest Service*

Table 1: *Roundwood available for processing in the Republic of Ireland (2008–2011).*

	2008	2009	2010	2011
	000 m³ OB			
Imports less exports	106	−63	28	55
Coillte harvest	2,279	2,354	2,217	2,299
Private sector harvest	118	130	463	386
TOTAL	2,503	2,421	2,708	2,740

Source: Knaggs, G. and O'Driscoll, E. 2011. Woodflow and forest-based biomass energy use on the island of Ireland (2011) – COFORD Connects Processing/Products.

Forest-based biomass for energy use, policy drivers and markets

Past and current use

In 2010, 34% of the roundwood harvested in the Republic of Ireland was used for the production of biomass energy (Table 2). Since 2006, the use of wood biomass energy in Ireland has resulted in an estimated greenhouse gas emission saving of 2.03 million tonnes of CO_2.

The results of a recent study (referred to in O'Driscoll and Knaggs 2012) has shown that the Irish market for firewood has grown by 35% over the period 2006–2010. In 2010, 199,000 m³ of firewood was sold in Ireland to a value of €28.80 million. The harvest level is significantly above that which had been estimated for previous years and shows that the Irish firewood market is providing a

Table 2: *Use of forest-based biomass (in 000 m^3 over bark, round wood equivalent) and as a proportion of total roundwood harvest (2010–2011).*

	2010	2011
	000 m^3 OB RWE	
Forest-based biomass use by Edenderry Power	79	85
Forest-based biomass used for energy production and process drying in sawmills and wood-based panel mills	475	487
Roundwood chipped for primary energy use	39	41
Domestic firewood use	199	214
Short rotation coppice	1	5
Wood pellets and briquettes	121	129
Charcoal	2	2
TOTAL	**916**	**963**
Roundwood available for processing	2,708	2,740
Firewood harvest	199	214
TOTAL	**2,907**	**2,954**
Forest-based biomass as a % of total roundwood harvest	**31.5**	**32.6**

Source: UNECE Joint Wood Energy Enquiry (JWEE): 2009–2012.

steady and a growing market for first thinnings. An important consideration here is the need for advice on efficient and environmentally friendly wood fuel combustion systems, such as wood gasification boilers.

The use of forest-based biomass for energy production is dominated by the forest products sector, which uses it for process drying and for energy purposes. Since 2007, the use of forest-based biomass for energy production by commercial and domestic users has risen considerably (Table 3). Between 2005 and 2009, the

Table 3: *Wood biomass fuel use by sector in the Republic of Ireland (2008–2011).*

Fuel category	**End use**	**000 m^3 RWE**			
		2008	**2009**	**2010**	**2011**
Firewood	Domestic heating	171	184	199	214
Wood chips	Commercial heating	63	53	39	41
Short rotation coppice (SRC)	Commercial heating	1	4	1	5
Wood pellets and briquettes	Domestic and commercial heating	82	110	121	129
Charcoal	Domestic use	2	2	2	5
Biomass use by the energy and forest products industry	Process drying/heating /CHP	384	438	554	572
TOTAL		**703**	**791**	**916**	**966**
Use by the energy and forest products sectors (%)		55	55	60	59

Source: Knaggs, G. and O'Driscoll, E. 2011. Woodflow and forest-based biomass energy use on the island of Ireland (2011) – COFORD Connects Processing/Products.

Table 4: *Output use of forest-based biomass and associated greenhouse gas emissions mitigation (2008–2011).*

	Unit	2008	2009	2010	2011
		Output			
Heat	TJ	4,857	5,273	6,306	6,604
Electricity	TJ	112	240	372	378
TOTAL	TJ	4,969	5,513	6,678	6,982
CO_2 abated	000 tonnes	380	422	511	534

Source: Knaggs, G. and O'Driscoll, E. 2011. Woodflow and forest-based biomass energy use on the island of Ireland (2011) – COFORD Connects Processing/Products.

domestic use of forest-based biomass grew by 18% per annum. The output of the forest-based biomass energy sector is shown in Table 4.

Projected forest sector contribution to supply and demand of biomass

Work on forest-based biomass supply and demand has been published in two COFORD reports issued in early 2011:

a) The All-Ireland Roundwood Production Forecast 2011–2028 (Phillips 2011) covers all roundwood but includes separate estimates of forest-based biomass supply to 2028 (Table 5). It estimates that annual net realisable roundwood volume production will increase to 4.64 million m^3 by 2020 and shows that supply of forest-based biomass has the potential to increase by up to 50%, or 1.5 million m^3 by 2020. The report notes: "The total is not an estimate of new or additional volume available for wood energy over and above current usage. Wood energy will have to compete with other end uses for the volumes indicated." There is potential to increase the level of supply of forest-based biomass in the period up to 2020 by:
    1. harvesting occurring in a higher proportion of forests that are due for thinning;
    2. removing larger amounts of biomass in thinning by using whole-tree harvesting systems (Kent et al. 2011); and
    3. removing harvesting residues and stumps from selected clearfell sites (Kent 2012).

b) The All-Ireland Roundwood Demand Forecast 2011–2020 (COFORD Roundwood Demand Group 2011) estimates that annual demand for roundwood will increase to ca. 6.04 million m^3 by 2020, including an estimated demand of 3.08 million m^3 of wood biomass for energy purposes. The estimated shortfall in supply of roundwood is around 1 million m^3 on the island of Ireland by 2020, mainly in the Republic of Ireland and almost all in the forest-based biomass category. The shortfall could be partly addressed by recovery of harvesting residues from suitable clearfell sites, and from increased fibre recovery from first and subsequent thinning. In addition, short rotation coppice could make a contribution to closing the

Table 5: *Estimate of wood fibre potentially available for energy (in 000 m³) and its energy content. (PCRW = post-consumer recovered wood.)*[a]

Year (PJ)	Tip to 7 cm	Roundwood 7–13 cm	Downgrade + wood residues	PCRW	Total	Energy content
2011	48	199	737	86	1,069	7.38
2012	45	202	626	87	959	6.61
2013	44	177	639	88	948	6.54
2014	47	203	726	88	1,065	7.35
2015	48	232	735	89	1,104	7.62
2016	48	251	692	91	1,083	7.47
2017	52	303	734	93	1,182	8.16
2018	50	265	712	95	1,122	7.74
2019	53	296	784	97	1,230	8.49
2020	58	382	915	99	1,453	10.02
2021	59	374	910	101	1,444	9.97
2022	59	369	901	103	1,431	9.88
2023	63	378	982	105	1,527	10.53
2024	60	369	942	107	1,478	10.20
2025	56	325	882	109	1,372	9.47
2026	55	331	1,052	111	1,549	10.69
2027	63	398	1,236	113	1,809	12.49
2028	61	382	1,191	116	1,750	12.07
Total	**970**	**5,435**	**15,395**	**1,776**	**23,575**	**162.67**

Source: Phillips, H. 2011. *All-Ireland Roundwood Production Forecast 2011–2028*. COFORD, Department of Agriculture, Food and the Marine, Dublin.

[a] There are three main sources of raw material for wood energy – small roundwood from thinnings, wood residues from the processing sector and post consumer recycled wood (PCRW). Additional raw material is potentially available through the harvesting of tree tips (tip to 7 cm diameter) and through the collection of harvesting residues and some harvest-abandoned material on suitable sites.

anticipated supply gap. Supply could be supplemented by areas of short-rotation coppice and short-rotation forestry[2].

Forest-based biomass is by far the dominant component of biomass supply and is likely to remain so. Recent work (Phillips 2012) points to an afforestation level approaching 15,000 ha per annum in the period leading up to 2020 and beyond, as necessary for forests to provide a sustainable level of supply of forest-based biomass.

[2] In this context short rotation forestry is a tree crop grown on a typical cycle of 10-15 years followed by regeneration. Short rotation coppice includes tree species such as willow harvested on a two to three year cutting cycle with the stools being replaced every 20 to 24 years.

Economic output and employment in the forest sector

The contraction in the domestic economy since 2007 has been balanced by a significant increase in wood product exports. In value terms, exports of wood products grew by 18% in 2010 to reach €286 million, €179 million of which comprised wood-based panels. This was largely due to increased demand in the UK as a result of reduced production of wood products in the Nordic countries in response to falling markets and the ability of Irish sawmillers to adapt to changing market conditions.

The increasing use of wood biomass in the renewable energy sector is also providing private forest owners with a long term sustainable market for wood, especially for small-diameter logs and harvesting residues from early thinning operations. Use of forest-based biomass is likely to increase substantially with the availability of REFIT 3 from early 2012. At the end of 2010, Ireland's consumption of electricity from renewable sources stood at 14.8% and this needs to increase to 40% by 2020, if we are to meet our legal obligations. In order to contribute towards our target, REFIT 3 sets out to encourage the development of biomass resources through REFIT (Renewable Energy Feed in Tariff) for biomass generation.

Economic output for the forest sector can be divided into the growing and processing subsectors. In 2010, direct output of the growing subsector was €379.8 million (Ní Dhubháin et al. 2012). When the indirect effects (i.e. the impacts of the spending by suppliers to the growing sector on goods and services) and induced effects (i.e. the additional consumer expenditure that takes place when the wages and salaries generated from the direct and indirect contributions of the growing subsector are in turn spent) are taken into account, the overall value of the growing subsector to the Irish economy was €673.0 million in 2010. Direct employment was 3,125. Accounting for the induced and indirect effects, the total employment supported by the growing subsector was estimated to be 5,531.

Direct output in the processing subsector (panel board mills, sawmills and other wood products) was €1,330.9 million. Direct employment was 3,907. Accounting for the induced and indirect effects, the total employment supported by the processing subsector was estimated at 6,408. The total value to the economy of the processing subsector was €2.20 billion, nearly 3.3 times the growing subsector figure of €673.0 million (Ní Dhubháin et al. 2012).

The future of forestry: fundamental issues

Heretofore, the main focus underpinning forest policy was to ensure a consistent, continuous supply of roundwood to the wood processing industry. In latter times, this focus has extended to encompass renewable energy policies and associated measures (through the provision of wood biomass for the wood energy sector – thereby also developing a market for thinnings) and climate change mitigation (Government of Ireland 2012). At the same time, the emphasis on the environmental and societal benefits associated with forestry has also increased.

In order to continue to develop forestry into the future for the above purposes, particularly the productive functions, and to ensure it is "fit for purpose" into the future, it is important to assess the following fundamental issues as they apply to forestry in Ireland:

- appropriate level of afforestation;
- efficient and economic management of the current forest estate;
- cost-effective mobilisation of roundwood timber from the forest estate;
- silviculture and management systems;
- the sustainability of residue and stump harvesting;
- optimal use of wood;
- sustained provision of public goods;
- forest protection and health;
- governing legislation.

Afforestation

The main focus is to increase the level of annual afforestation to 14,700 ha, in line with the commitment in the Programme for Government. This level of afforestation, if sustained over an extended period of two decades, would contribute to achieving a sustainable supply of goods and services from the forest sector. Given the current annual afforestation levels of ca. 6,000 ha, this target seems to be quite unrealistic. Additional factors to be considered in this context are:

- the species mix that would take account of the implications of climate change, future market requirements and carbon sequestration capacity;
- the necessity to comply with environmental and regulatory procedures; and
- the availability of suitable land.

While the availability of funding is a major factor limiting the ability to achieve this target, there are also other contributory factors including the attitude of landowners to forestry. The provision of information on forestry, especially in relation to cost and projected income (both in the short and long-term), will help to increase the return on investment, as will learning of the experiences of landowners who have already committed to a forest enterprise.

The management of the current forest estate

The effective and optimal management of the current forest resource is also essential in order to maximise the return to both the forest owner and the sector in the future. For the benefit of the overall sector, it is important, at a policy level, to support sustainable forest management (SFM), facilitate certification, have systems in place to forecast future roundwood supply and ensure compliance with felling requirements. It is therefore necessary to engage at forest owner level to convey the importance of sustainable forest management and certification. Certification of timber from sustainably managed forests has become a pre-requisite for the sale of processed timber into many timber outlets, particularly in the UK.

In recognition of the importance of the thinning of plantations, as and when appropriate, to ensure the viability of the remaining stand and to contribute to the long term financial return, it will also be necessary to focus on investment in the forest road infrastructure. Once again, the availability of funding will be a major determinant.

The mobilisation of timber from the privately owned forest plantations

A challenge that has been identified in relation to roundwood supply has been the mobilisation of the private timber resource. The age profile of the current forest estate and the need to leverage supplies from the private sector to meet the increasing demand for wood energy (met through the extraction of thinnings) have combined to highlight this issue. Research conducted by Teagasc indicates that if only 50% of private forest owners thin their plantations, the output from farm forestry first thinnings alone would exceed 200,000 m³ each year. Coillte is currently the main supplier of roundwood to the sawmilling / processing industries; however, COFORD estimates that the private sector's market share could rise from approximately 10% at present to 23% by 2015. There are at least three issues in relation to the extraction of roundwood from private forest plantations, namely:

- Strong demand for roundwood at prices that will enable and encourage private sector investment and involvement. This is allied to the policy and regulatory framework; for example the roll out of REFIT III and the consent system for forest roads.
- Knowledge about thinning: the forest owner knows the financial benefits and importance of thinning and how to go about it. This information is available in the private sector and through the Teagasc Forestry Development Department's Training and Advisory Programme. It is also being promoted through the formation of forest producer groups with the assistance of the Teagasc Forestry Development Department.
- The requirement for forest roads to facilitate the harvesting and extraction of the thinnings – also necessary in the long term for clearfelling (i.e. harvesting of final timber crop) – as outlined above, the availability of funding is a major determinant while compliance with planning regulations is also now a factor.

Silviculture and management systems

It has been demonstrated that changes in forest management can result in enhanced carbon sequestration and as a result a mitigation of climate change (Magnani et al. 2007, Ciais et al. 2008). However, a robust metrics system to compare the impacts of each forest management system on different ecosystem services is still missing. The overlapping challenge is to deal with the interactions between carbon sequestration and other forest ecosystem services (wood and non-wood products; wood for bioenergy; water quality and quantity; soil fertility and protection; recreation). Candidate silvicultural and management practices to increase climate change mitigation capacities in managed forests may include:

- afforestation/reforestation with species adapted to climate change;
- the use of mixed stands (for better use of soil resources and potentially increased resilience to climatic events);
- the use of coppice and coppice with standards (for an increased carbon storage in the roots and the provision of wood for energy);
- changes in rotation length (longer periods for a better nutrient use-efficiency,

versus shorter periods due to an increased sensitivity to climatic events and other risks such as pests, fires, etc.);
- adapted thinning and clearfelling schedules and intensities (to reflect a stand's sensitivity to storms); and
- appropriate forest fertilisation (to increase wood production and nutrient exports compensation).

These forest practices may potentially attenuate global warming through carbon sequestration, but they may lead to other biophysical changes that can enhance or diminish this effect.

The sustainability of residue and stump harvesting

Stump and root harvesting is increasingly practised in Scandinavia, and the techniques involved are now becoming established in the British (Moffat et al. 2011), and to a lesser extent in the Irish, forest sectors. However, analysis of available evidence has shown that under certain conditions these harvesting operations pose a significant risk to the environment and to sustainable forest management (Whittaker et al. 2011). Walmsley and Godbold (2010) identified many practical and perceived benefits of stump harvesting, including: 1) the production of woodfuel; 2) fossil fuel substitution; 3) additional revenue for forest owners; 4) improved site preparation and 5) potential reduction of the root rot *Heterobasidion*. However, evidence suggests that, in the absence of appropriate precautionary measures, stump harvesting will also lead to many undesirable environmental impacts. These include: 1) removal of soil organic matter inputs; 2) adverse impacts on forest soil carbon stores and greenhouse gas emissions; 3) increased soil erosion; 4) increased soil compaction; 5) depletion of soil nutrient stocks and changes in nutrient cycling; 6) unknown impacts on future productivity; 7) loss of valuable habitat for fungi, mosses, bryophytes and insects and 8) increase in non-forest vegetation and additional herbicide requirements. Environmental impacts tend to be greater in the uplands due to the preponderance of poorly drained, nutrient poor, carbon rich and acidic soils. Forest Research (2009a and b) in Britain developed operational guidelines in relation to stump harvesting and brash removal; however, research is required to understand fully the environmental impacts, particularly how stump harvesting influences the forest soil carbon balance and forest nutrient stocks.

The longer-term effects of intense biomass removal from a range of forest sites in the UK were investigated by Mason et al. (2012). They analysed three experiments that were established in the 1990s to examine the impact of complete residue (brash) and above-ground biomass removal (i.e. whole-tree harvesting) at clearfelling on the subsequent growth and yield of replanted Sitka spruce (*Picea sitchensis* (Bong.) Carr.). After 10 years at the two medium-risk sites, the growth in plots with brash retained was 5–9% greater for height and 5–7% greater for diameter than in plots where brash had been removed. However, at the poorest site, the equivalent differences were ~9% and 19%.

Forest protection and health

Not only is it important to increase the forest estate in size, it is also important to put in place the necessary conditions to protect and maintain the existing, growing forest. Current risks that need to be addressed include damage from deer, potential loss due to forest fires, pests and disease. In relation to damage by deer, the development of deer management policy addressed by the Forest Policy Review Group and the Inter-Agency Group on deer, which have widely consulted with stakeholders, have a recommendation to establish a permanent deer management competence in the public forest sector. Work is ongoing in relation to the implementation of the recommendations of the Forest Service Land and Forest Fires Working Group – once again this requires collaboration with the Local Authorities and relevant stakeholders to facilitate a co-ordinated system of fire plans for forest plantations. The Department of Agriculture, Food and the Marine will continue to identify pest risks and maintain biosecurity and phytosanitary measures addressing pests, diseases and invasive alien species. However, the vigilance of forest owners, and their active involvement in identifying and implementing measures to deal with risks, is a key element in the protection of the forest estate.

Optimal use of roundwood

Managed forests serve as a store of carbon and a renewable source of energy and materials. By using forest products as substitutes for fossil fuels or non-renewable materials, emissions from fossil C sources can be displaced. The efficiency of emissions displacement depends on the product, its lifecycle and the fossil-fuel based reference system that is substituted. Thornley and Cannell (2000) calibrated a mechanistic forest-ecosystem simulator, which couples carbon, nitrogen and water to mimic the growth of a pine plantation in a Scottish climate. They concluded that there is no simple inverse relationship between the amount of timber harvested from a forest and the amount of carbon stored in the forest. Pingoud et al. (2010) developed an integrated, steady-state analysis comparing various equilibrium states of managed forests and wood product pools that represent sustainable long-term forestry and wood-use strategies in Finland. When sawlog supply is directed to production of long-lived materials substituting for fossil-emission and energy intensive materials, and recycled after their useful life to bioenergy, the benefits for the climate were greatest. Hofer et al. (2007) carried out a similar study in Switzerland. Recommendations resulting from this study were:

1) the maximum possible increment that is also sustainable should be generated in the forest;
2) this increment should be utilised through wood harvesting;
3) the harvested wood should be processed in accordance with the principle of cascaded use[3]; and
4) waste wood that is not suitable for further use should be used for energy generation.

Haberl and Geissler (2000) identified similar benefits of cascade utilisation of

[3] Cascade use involves first using the wood in solid wood products and other longer term end-uses and then reusing or recycling the materials when they have come to the end of service and where it is no longer feasible to combust the material.

biomass. A detailed study of the energy and carbon balances of various cascade chains for recovered lumber was carried out by Sathre and Gustavsson (2006). Energy and carbon balances of chains of cascaded products were compared to the balances of products obtained from virgin wood fibre or from non-wood material. The authors found that land-use effects had the greatest impact on energy and carbon balances, followed by substitution effects, while direct cascade effects were relatively minor. In a study by Backéus et al. (2006), mitigation of carbon emissions through carbon sequestration in forest biomass and the use of forest biofuel for fossil fuel substitution were considered for northern Sweden. The objective was to maximize the combined net present value for harvested timber, biofuel production and carbon sequestration. Increasing the carbon price led to decreasing harvest levels of timber and decreasing harvest levels of forest biofuel. Also, thinning activities decreased more than clearcut activities when the carbon prices increased.

An alternative use of biomass to burning is conversion to chemicals and energy through biorefining. Biorefining is a concept for the collection of processes used to convert biomass to chemicals and energy (Amidon et al. 2008). Ragauskas et al. (2006) carried out a review of the potential contribution of the forest products industry to liquid biofuel production in the United States. They identified that the forest products industry was one of a few nationally based industries that had the necessary skill-set and infrastructure available to process sufficient biomass for the rapid, short-term development and commercialisation of biofuel and biochemical technologies. Their review describes the operational considerations by which the biofuels and pulp industries could operate in synergy. Pu et al. (2008) also identified the importance of research into cellulosic ethanol to generate higher volumes of biofuels at lower cost. Their review examined the major chemical constituents of biomass and the recent advances in their conversion to biofuels, with a special emphasis on the conversion of forest residues and woody-energy crops to bioethanol.

Potential for perverse incentives

The rapid rise in crude oil prices and the geo-political uncertainty associated with ensuring uninterrupted supplies have compelled researchers, economists and politicians to look for indigenous substitutes (Srinivasan 2009). Before investing public and private resources towards biomass production, the sustainability of these production systems should be considered carefully, with the ecological limits of forests clearly identified and understood (Hesselink 2010). Perverse incentives should be avoided; a precautionary path is therefore required that makes ecosystem sustainability a priority, and that operates under a regulatory regime that integrates bioenergy harvesting in forest management plans. Schubert and Blasch (2010) showed that under free market conditions, undersupply of sustainable bioenergy will prevail. Two types of market failures – information asymmetry and externalities in bioenergy production – will lead to less sustainable bioenergy production. The authors concluded that to regulate the bioenergy market, mandatory certification combined with binding minimum standards are required. Likewise, Smith et al. (2011) argued that while biological carbon dioxide removal may play a valuable role in future climate change mitigation, many of its proponents fail to account for the full range of biological, biophysical, hydrologic, and economic complexities associated with proposed land-use changes. At a more immediate scale, Searchinger et al. (2009) identified that the accounting used for assessing compliance with carbon limits in the Kyoto Protocol and in climate legislation contained a flaw which treated all bioenergy as carbon neutral, regardless of the source of the biomass. For example, the clearing of long-established forests to burn wood or to grow energy crops is counted as a 100% reduction in energy emissions, despite causing large releases of carbon. These issues have been addressed to some extent in the LULUCF rules agreed at Durban (UNFCCC/2/CMP.7). These deal with developed countries and extend mandatory accounting to all managed forests and provide a way to better account for harvested wood products. A critical consideration is how many parties will agree to emission reductions for the post 2012 period and then the extent to which they will include the LULUCF sector in commitments. If emissions are not accounted for in the forest sector then the carbon-neutral accounting arrangement for wood fuels can be called into question. An even larger issue is when and to what extent developing countries will enter an accounting framework that will enable emissions from biomass harvest to be accounted and netted-off. The EU's Renewable Energy Directive does address the accounting of greenhouse gas emission savings from liquid biofuels and has a range of qualitative criteria for solid biomass. The European Commission has recently undertaken consultations on the need to update criteria for solid biomass to qualify for meeting renewable energy targets.

Public goods arising from forestry

There has been growing recognition of the non-wood benefits of forestry (Upton et al. 2012). The public goods most commonly associated with forestry include:

- leisure and recreation – with benefits for public health;
- landscape;
- climate change mitigation – particularly carbon sequestration;
- soil and erosion control;
- bio-diversity and conservation.

While ascribing values to non-wood benefits can be difficult, they were estimated at over €88 million per annum by Bacon and Associates (2004). It is estimated that the carbon sequestrated by Irish forests could be worth an average of €33 million annually for the first commitment period of 2008–2012 inclusive.

In relation to climate change mitigation, as the ownership and liability for carbon stocks resides with the State, the carbon stocks from the forest estate (planted post 1990) form part of the compliance accounting framework when calculating Ireland's liabilities. From 2013, all forests will come under a new EU-wide reporting and accounting framework. Harvest levels in pre-1990 forest (85% of which are owned by Coillte) will be included for the first time. Under the new rules agreed at Durban at the end of 2011, Ireland has a projected business-as-usual level of harvest in pre-1990 forests over the period 2013–2020. An increase in harvest levels over business-as-usual would result in debits at national level.

However, increasing Ireland's forest cover and avoiding deforestation (permanent removal of forest cover) would ameliorate any potential deficit.

Governing legislation
The current legislative basis for the regulation of forestry is the Forestry Act 1946 as amended. The drafting of a Bill (the Forestry Bill) to replace it is at an advanced stage of preparation. The Bill was presented to the Dáil (parliament) in April 2013 and will be subject to the parliamentary process over the course of 2013. In view of the nature and extent of changes over the intervening 66 years, the overall purpose of the Bill is to update provisions in relation to felling and other associated matters.

Research needs
Based on the above discussion of important issues that the forest sector faces in the future, the following main research needs have been identified:

- factors affecting the afforestation programme: land availability and suitability; environmental constraints; attitudinal, socio-economic factors; and grant schemes;
- tree improvement, silviculture and integrated forest management systems, including cascade utilisation of wood and life cycle analysis of wood products;
- wood supply chain technology and logistics;
- sustainability and certification of removal of harvesting residues and stumps;
- bio-refinery and other new uses of wood;
- carbon and greenhouse gas dynamics associated with land-use change and in the full range of forest types and for all management systems;
- forest adaptation, both at the medium and long-term, to ensure a sustained provision of public goods under climate change conditions.

It should be noted that the COFORD Council, within the Department of Agriculture, Food and the Marine, has set up a Forest Research Working Group to develop a national strategic research agenda for the forest sector for the period 2013–2017. This agenda should underpin competiveness and environmental performance, with reference to previous national forest policy initiatives, the work of the Forest Policy Review Group, Food Harvest 2020, the National Research Prioritisation Exercise and other relevant policies, such as the National Renewable Energy Plan. The research needs identified in this paper, especially those related to the green economy, will feed into this national research agenda.

Conclusion
The forest sector plays and will play an important role in relation to climate change mitigation and the development of a green economy. It is important to develop and implement sector specific policies and measures that will enable this role and potential to be expressed in a coherent and cost-effective manner. Likewise, the role of the forest sector across the green economy and in national greenhouse gas mitigation and climate change adaptation strategies needs to continue to be clearly reflected in policies in these areas. By mobilising the forest sector's potential, the

task of decarbonising the Irish economy over the coming decades will be easier to achieve in a cost effective and sustainable manner.

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Current and emerging threats to Ireland's trees from diseases and pests

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Abstract

Over the past decade the number of new pests and diseases detected in the United Kingdom and Ireland has increased significantly, particularly on trees and woody ornamentals. Whilst there has been a wide range of pests and diseases affecting woody hosts, those caused by members of the genus *Phytophthora* have been very damaging and widespread. These include *P. ramorum* on larch and rhododendron, *P. lateralis* affecting Lawson cypress, *P. kernoviae* on beech (*Fagus sylvatica* L.) and *P. pseudosyringae* infecting *Nothofagus* and bilberry species. Other recently introduced pathogens are responsible for causing the diseases red band needle blight (*Dothistroma septosporum*), ash dieback (*Chalara fraxinea*); and horse chestnut bleeding canker (*Pseudomonas syringae pv. aesculi*). A number of invertebrate pests also pose significant threats to Ireland's trees including, oak processionary moth (*Thaumetopoea processionea*), pine processionary moth (*Thaumetopoea pityocampa*), horse chestnut leaf miner (*Cameraria ohridella*), Asian longhorn beetle (*Anoplophora glabripennis*), and pine wilt nematode (*Bursaphelenchus xylophilus*). A number of factors have contributed to this increase. In recent years there has been an upsurge in the global trade of plants, which are being moved more rapidly from country to country. Small changes in temperature or weather patterns, due to climate change, can enable organisms to become established in areas where previously they would have struggled to survive. Often phytosanitary regulations and how they are applied are not as robust as they might be. Furthermore there is a general lack of understanding in the general public of the importance of being vigilant in keeping pests and diseases out of the country. In Ireland there is a better chance of remaining free of many pests and diseases not currently found on the island.

Keywords: *Phytophthora ramorum, P. lateralis, P. pseudosyringae, Chalara fraxinea, Global plant trade, Phytosanitary measures, Pseudomonas syringae pv. aesculi, Dothistroma septosporum.*

Introduction

During the past 10 years or so there has been a very significant increase in the incidence of diseases and pests affecting trees in Europe including the UK and Ireland. Several new pathogens have been named and the impact of pests and diseases on tree health has been obvious. Perhaps for the first time for many years, going back to the Dutch elm disease outbreak of the 1970s, there is public awareness of the importance of plant health and of the work done by plant pathologists and entomologists.

Ireland, as an island, is currently free of many damaging plant pest and

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pathogens, which have been introduced into other regions of the European Union, where some have become established and are causing serious problems. In this paper some of the major new diseases and pests which have been identified in trees and woody plants in Ireland are highlighted. Some of the reasons for their increased incidences are advanced, together with some speculation as to new threats on our door-step from diseases and pests that are not currently in Ireland. Finally a number of observations are made on issues and challenges facing the plant health authorities in their attempts to maintain this high plant health status.

Recent tree disease introductions to Ireland

Ireland, being an island off the north-west coast of continental Europe has some advantages in protecting its high plant health status. Prevailing winds tend to be from the west and so the risk of aerial spread of disease is reduced. Great Britain often acts as an "early warning system" for new organisms. For example fireblight, caused by the bacterium *Erwinia amylovora* (Burrill) Winslow et al. was first observed in Kent in south-east England in 1957, but not detected in Ireland until the mid 1980s (van der Zwet 2002). The main route of entry for pests and pathogens is almost certainly movement of plants and plant products either in trade or by members of the public (Brasier 2008).

Despite these advantages, a number of new pest and diseases have been found in recent times and threaten our high plant health status and our trees (Table 1). These topics are dealt with in more detail below.

Phytophthora ramorum (Sudden oak death; ramorum disease)

Phytophthora ramorum is a fungus-like organism with a wide host range. It was first identified around the year 2000 as the organism responsible for the death of large numbers of tanoak (*Lithocarpus densiflorus* (Hook. and Arn.) Reh.) in California (Rizzo et al. 2002). Mature trees died quickly, hence the disease became known as called "sudden oak death" (SOD). At about the same time in The Netherlands and Germany the pathogen associated with dieback and blight of rhododendron (*Rhododendron ponticum* L.) plants was also identified as *P. ramorum* (Werres et al. 2001). It therefore seemed that this "new" pathogen had been found affecting two very different hosts in two distinct geographic regions. It was subsequently shown that the two pathogen populations were predominantly of different sexual mating types. The European population was classified as A1 while the US population was A2. This suggests that there were probably two separate introductions. Both introductions may have occurred at different times, possibly from the Far East, although at present that is still conjecture. What is clear is that the European introduction was not directly associated with the American outbreak and vice versa. A full updated EU Pest Risk Analysis (PRA) for *P. ramorum* has been published (Anon. 2009), as has an extensive data sheet about the pathogen (Anon. 2007).

The first finding, in 2002, of *P. ramorum* in the UK was on *Viburnum* spp. growing in a garden centre. Although *P. ramorum* has been shown to have a wide host range (>100 species; Grünwald *et al*. 2008), initially most of the infections in

Table 1: Diseases and pests of concern to Irish trees and forests.

Disease	**Causal agent**	**Main hosts of concern**	**EPPO status**	**First report in Ireland**	**Level of concern**
Ramorum disease, (Sudden oak death)	*Phytophthora ramorum* Werres, De Cock & Man in't Veld	Japanese larch, rhododendron, oak, Douglas fir, bilberry, and 100+ other hosts	Alert list PRA (Anon 2007; Anon 2009)	2006	High
Lateralis diease	*Phytophthora lateralis* (Tucker & Milbrath)	Lawson cypress	A2 PRA (Anon. 2006)	2010	Low
Kernoviae disease	*Phytophthora kernoviae* (Brasier, Beales & S A Kirk)	Larch, rhododendron bilberry, beech, oak	Alert list PRA (Anon. 2008a)	2009	Medium
Pseudosyringae disease	*Phytophthora pseudosyringae* (Jung)	Beech, *Nothofagus* spp. Pieris, oak, bilberry	PRA (Anon. 2012a)	2011	Low
Red band needle blight	*Dothistroma septosporum* (Dorog): *Mycosphaerella pini* (E. Rostrup) syn.	Corsican pine, Scots pine	PRA (Anon. 2013a)	2011	High
Ash dieback	*Chalara fraxinea* (T. Kowalski): *Hymenosscyphus pseuodalbidus* (teleomorph)	*Fraxinus excelsior* *F. nigra* *F. angustifolia*	Alert list PRA (Sansford 2013)	2012	High
Horse chestnut bleeding canker	*Pseudomonas syringae pv. aesculi* (Durgapal & Singh)	Horse chestnut	-	2010?	Medium
Oak processionary moth	*Thaumetopoea processionea* (L.)	Oak	PRA (Evans 2007)	Not reported	Medium
Pine processionary moth	*Traumatocampa pityocampa* (Den. & Schiff.)	*Pinus* spp. Especially: Austrian, lodgepole, Scots, Monterey	-	Not reported	High
Horse chestnut leaf miner	*Cameraria ohridella* Deschka & Demic	*Aesculus* spp. in particular the European white-flowering horse-chestnut	PRA (Stigter 2000)	Not reported	Low
Asian longhorn beetle	*Anoplophora glabripennis* (Motschulsky)	Maple, horse chestnut, alder, birch, poplar, willow, elm + many other broadleaf trees	PRA (van der Gaag, 2008)	Not reported	High
Pine wilt nematode	*Bursaphelenchus xylophilus*	*Pinus* spp. including Scots, Austrian and red pines	A2 PRA (Evans et al. 1996; Evans et al. 2009)	Not reported	High

the UK and Ireland were reported on rhododendron with *R. ponticum* being particularly susceptible. Infected plants were found in both garden / parkland situations and also in forest situations. Rhododendron was recognised as a sporulating host and primary source of inoculum. Where mature broadleaved trees, e.g. *Quercus* and *Fagus* spp. etc. were found to be infected with *P. ramorum*, they were always associated with infected rhododendron, often in actual contact with the affected trees. In the Pacific oak forests of south-western USA, bay laurel (*Laurus nobilis* L.) serves a similar role as a primary sporulating host acting as the source of inoculum infecting mature trees.

The situation changed, however, in 2009 when *P. ramorum* was shown to be causing the death of mature Japanese larch (*Larix kaempferi* (Lam.) Carr.) trees in south-west England (Brasier and Webber 2010) (Figure 1). In many of the subsequent cases no infected rhododendron was found in close proximity to the larch. Furthermore in contrast to other tree species, larch was shown to be a major sporulating host, producing up to 10 times more sporangia on larch than on rhododendron. As sporulation was occurring in the canopy at heights of up to 20–25 m, the potential for widespread dissemination was significantly greater.

The approach in both the UK and Ireland to outbreaks of *P. ramorum* in larch still continues to be one of eradication (Anon. 2013a). In Great Britain over 3,000 ha of larch have been cleared since 2009. In N. Ireland around 500 ha out of a total larch area of approximately 5,000 ha have been cleared. Recent results from the Forestry Commission in Britain show a slowing down of the spread in England, while the disease continues to expand considerably in larch plantations in Scotland, particularly in the Dumfries and Galloway region. Aerial spring and autumn surveys of larch plantations in N. Ireland have subsequently shown a slowing of the spread, although there is evidence that the disease is still moving northwards. The majority of outbreaks in N. Ireland have been on the east of the Province, with the primary focus of infection being on the Antrim Plateau with a further pocket of outbreaks in southern Co. Down. In late 2012, *P. ramorum* was found causing symptoms on noble fir (*Abies procera* Rehder) and larch trees in a plantation in south Armagh. In summer 2013 there was evidence that the pathogen had spread westwards with a number of small outbreaks in Co. Tyrone and Co. Fermanagh. These infected sites tended to have only a few trees showing symptoms which were much less severe than in the main areas of infection in Co. Antrim. In the Republic of Ireland, outbreaks have been mainly in the south eastern part of the island.

As already indicated, two mating types A1 (European) and A2 (American) are known to exist. There have been a small number of records of A1 types being found in America and the A2 mating type has been detected once in Belgium (Grünwald et al. 2008). There have been no records of the production of viable oospores in the wild; however, oospore formation on living plants under controlled conditions has recently been recorded (Riedel et al. 2012). The rare occurrence of *P. ramorum* oospores in-vivo supports the hypothesis that the American and European populations of the pathogen belong to different clonal lineages. Up until 2010 only three lineages of *P. ramorum* were known. Two (NA1 and NA2) were found in America and one (EU1) was the only lineage known in Europe, having been

Figure 1: *Aerial shot of larch forest with* Phytophthora ramorum *infected trees.*

introduced in the early 1990s. However, in 2011 a new lineage designated EU2, was described (van Pouke *et al*. 2012). Most of the EU2 isolates were obtained from Northern Ireland, with a small number from the south-west corner of Scotland. EU2 isolates were obtained from larch, rhododendron, *Vaccinium* spp. and oak, but were not found in any of the other regions of Europe where *P. ramorum* occurred.

In a recent extensive study of over 300 isolates or DNA extractions of *P. ramorum* from both the north and south of Ireland, genotyping to either EU1 or EU2 was carried out (Mata Saez, personal communication). The vast majority of the isolates were obtained from samples submitted between 2008 and 2013 to the Agri-Food and Biosciences Institute, Belfast or the Department of Agriculture, Food and the Marine laboratories, Backweston and represented a wide range of forestry, nursery and natural sites. Isolates had been obtained from a wide range of hosts including Japanese larch, noble fir, rhododendron, red oak (*Quercus rubra* L), bilberry (*Vaccinium myrtillus* L.), *Viburnum* spp. Thunb. and beech (*Fagus sylvatica* L.). All of the isolates investigated so far by molecular methods have been A1 mating type. Preliminary data indicate that almost all of the N. Ireland isolates were EU2, and that this lineage was only recently introduced into Northern Ireland (van Pouke et al. 2012). A small number of *P. ramorum* EU2 isolates were also found in trees in south-west Scotland in the Dumfries and Galloway region. There is no definitive evidence about the source of EU2 or whether it spread east or west in the wind or through movement of contaminated plants or soil. One small pocket of EU1 isolates in N. Ireland was associated with a landscape planting of recently imported rhododendron plants from a nursery where EU1 *P. ramorum* had previously been detected. In contrast almost all of the isolates from the Republic of Ireland have been shown to be EU1 (Mata Saez pers. comm.). Much further work is needed as it is important to identify the source of the pathogen to determine the pathological significance of the EU2 lineage of *P. ramorum* and to suggest why it seems to predominate in such a small geographic region.

Phytophthora kernoviae

During surveys of woodlands in Cornwall, south-west England the discovery of a new *Phytophthora* sp. was reported – which was later named *P. kernoviae* (from “Kernow”, the Cornish word for Cornwall (Brasier et al. 2005)). It is particularly associated with bleeding stem lesions on mature *Fagus sylvatica* as well as with stem and foliar necrosis on *R ponticum.* Most of the outbreaks have been confined to the south-west of England. However in the past few years outbreaks of *P. kernoviae* have been commonly found in parts of Wales as well as in the west of Scotland on bilberry (*Vaccinium* sp.) and other hosts. Indeed, it is the damage caused to *Vaccinium* and *Calluna* species by *P. kernoviae* that is most worrying in Britain, as large scale death of these two species could threaten the integrity of heathland and the species within it (Beales *et al*. 2009a). *P. kernoviae* was first detected in Ireland in 2008 on *Rhododendron* spp. and confirmed in 2009 (Brennan et al. 2010). It is crucial that important *Vaccinium* heathlands in Ireland are surveyed regularly so that actions can be taken to prevent the spread of the pathogen to this ecologically significant species. The only other country in the world where *P. kernoviae* has been detected is New Zealand. It is only possible to speculate on the original source of the pathogen, however it seems probable that it was spread on infected plants in the horticultural trade. It has been isolated from the soil and was found infecting shoots and fruit of cheromoya (*Annona cherimola* Mill.), also known as custard apple (Ramsfield et al. 2009).

A revised PRA for the UK was published in 2008 (Sansford, 2008), which concluded that *P. kernoviae* continues to pose a threat to the managed and unmanaged environment, the timber and ornamental plant trade and the tourism industry in the UK. As with the disease management strategy for *P. ramorum*, removal of infected plants will reduce the inoculum and may significantly slow its subsequent spread and establishment.

Phytophthora lateralis

In 2010/11 *P. laterais* was isolated from diseased Lawson cypress (*Chaemecyparis lawsoniana* A.Murray. Parl.), at a range of sites in Scotland, England and Northern Ireland (Green et al. 2013). At the majority of the sites, only collar and root lesions were observed. However, at two of the sites large stem and branch lesions were observed which had no connection with the diseased collar regions. *P. lateralis* was isolated from these aerial parts of the plants. There is currently some debate about whether aerial infections occur, and if so, whether they are an important source of inoculum. In Taiwan, which is thought to be the centre of origin of the pathogen, sporulating aerial infections have been reported (Brasier et al. 2010). Possible aerial infections have also been observed in some of the outbreak sites in Scotland and France, however root infections with the associated dissemination are still regarded as the most important way for the pathogen to complete its life cycle.

In late summer 2010, *P. lateralis* was found to be associated with a number of

Figure 2: Phytophthora lateralis *infected Lawson cypress trees in Tollymore Forest Park, Co. Down.*

dead mature Lawson cypress trees in Tollymore Forest Park in south Down, N. Ireland (Figure 2). Further significant outbreaks were found at Somerset Forest Park in north Co. Derry, in a forest plantation at Mourne Forest in Co. Down and at several other smaller sites including private gardens, landscaped areas etc. The pathogen is a root-infecting organism and causes a large rusty brown lesion at the base of the tree, which often results in its rapid demise. The most probable routes for its dissemination are in soil water or movement of infected soil particles or plant parts.

The genomes of four isolates of *P. lateralis* from N. Ireland have recently been sequenced. This showed that *P. lateralis* shares 91.5% nucleotide sequence identity with *P. ramorum* (NA1 lineage) over the conserved compartments of its genome. When individual isolates were compared they were almost identical, although there were several single nucleotide polymorphisms (SNPs) that distinguish between isolates. This may give potential markers for further molecular studies (Quinn et al. 2013).

Phytophthora pseudosyringae

In 2012 a new disease was reported on *Nothofagus* spp. in Britain, caused by *P. pseudosyringae* (Scanu et al. 2012). In Europe, *P. pseudosyringae* causes a root and collar rot of *Fagus sylvatica*, *Alnus glutinosa* L. Gaertn and *Carpinus betulus* L. (Jung et al. 2003; Denman et al. 2009, Scanu *et al*. 2010) and a foliar blight of *Vaccinium myrtillus* (Beales *et al*. 2009b). In late 2008 a severe outbreak of ink disease, usually associated with *P. cambivora* (Petri) Buisman, was observed in a *Castanea sativa* (Mill.) grove in the Sardinia region of Italy. Infected trees displayed microphylly, i.e. smaller leaves than normal, yellowish foliage and lesions on the main roots and collar (Scanu et al. 2010). In 60% of *P. cambivora* infected trees, *P. pseudosyringae* was also detected. There had been a previous report of *P. pseudosyringae* as the causal agent of stem necroses on chestnut seedlings in a nursery in Spain (Pintos Varela et al. 2007). In addition to records on plant and tree species *P. pseudosyringae* has also been detected in forest soils and streams in Scotland (Scibetta 2007) as well as in forest soils and streams in Oregon and California (Reeser et al. 2006), North Carolina (Hwang et al. 2007, 2008) and Alaska (Reeser et al. 2011).

On *Nothofagus* plantations in England, Scotland and Wales it has been very damaging with up to 70% dieback and mortality of *N. obilqua* at some sites. In January 2009, plants of *Vaccinium myrtillus* (bilberry) in woodland on Cannock Chase, Staffordshire, were observed with symptoms of stem dieback, while others were dead. The causal organism was shown to be *P. pseudosyringae*, which was the first report on *V. myrtillus* (Beales et al. 2009b).

In late 2012 *P. pseudosyringae* was isolated from extensive bleeding cankers on mature beech (see Figure 3) growing in a large estate in Co. Down, N. Ireland. To date it has not been possible to determine the source of the infection, although the primary means of dissemination are on infected plants or soil (Sansford 2012). Apart from the bleeding cankers the beech trees have no other obvious symptoms. They are not regarded as an important inoculum source and so the infected trees have not been removed. They will be closely monitored and will be felled if the situation changes with time. The pathogen can sporulate on other hosts such as bilberry and *Nothofagus*.

A study of European isolates of *P. pseudosyringae* helps support the view that the pathogen may have been in Europe, including the UK, for a considerable time (Linzar et al. 2009). It is difficult to assess the potential impact of *P. pseudosyringae* because often with tree infections it is associated with other *Phytophthora* spp. However, it is considered to be very damaging to bilberry, which is a common and

Figure 3: *Bleeding cankers caused by* Phytophthora pseudosyringae *on beech tree trunk.*

environmentally very important heathland plant. Sansford (2012) concluded that *P. pseudosyringae* has already been present in the wider environment so no action is considered necessary. The situation in Ireland, north and south, is less clear, highlighting the need for intensive and regular surveys of important heathlands and bilberry habitats. At present it has not been detected in the wider environment, particularly on bilberry so it may be that it is not established in Ireland. However, there is an urgent need to conduct a wider survey of heathlands in order to determine the extent of the pathogen's distribution.

Chalara fraxinea (ash dieback)
Ash dieback is a highly destructive emerging disease that is killing common and narrow-leaved ash trees (*Fraxinus excelsior* L. and *F. angustifolia* Vahl.) across Europe. Since the 1990s, serious decline of ash has been observed in central and northern Europe resulting in the widespread death of ash trees in Poland (Kowalski 2009), Hungary (Szabo, 2009), Austria (Halmschlager and Kiristis 2008), Sweden

(Bakys et al. 2009a), Norway (Talgo et al. 2009), Slovenia (Ogris et al. 2009), Italy (Ogris et al. 2010), Belgium (Chandelier et al. 2011), France (Husson et al. 2011), Croatia (Baric 2012) and southern Germany (Metzler 2012).

The sexual stage of *C. fraxinea* is *Hymenoscyphus pseudoalbidus*. It forms small fruiting bodies called apothecia from which ascospores are released (Figure 4). Apothecia are formed on fallen leaf rachises and leaf petioles and develop in the period June – October (Timmermann et al. 2011, Gross et al. 2012). The asexually formed spores appear to be non-infective and probably act as spermatia in the sexual life cycle. It has been suggested that leaf infection must re-occur each year. Even in an infected tree, while the pathogen can survive within the stem, it may not induce leaf symptoms and hence does not lead to apothecial formation. This could have a significant impact on the potential effectiveness of current eradication methods, halting the spread before the disease can become established in the wider environment. However it should be noted that this still requires further research before it is confirmed. The fungus has also been isolated from symptomless *F. excelsior* petioles (Bakys et al. 2009b). It is suggested that these are initial yet latent infections, or that *C. fraxinea* is also a natural endophyte of *F. excelsior.* Vasaitis (2012) postulates that this would imply a universal infection biology and life style of the fungus, possessing the fascinating ability to act as an endophyte, pathogen and saprotroph.

The first finding in Ireland and Britain of ash dieback caused by *Chalara fraxinea* (anamorph *Hymenoscyphus pseudoalbidus*) was in a nursery in Buckinghamshire in early 2012. The first case in the Republic of Ireland in Co. Leitrim, was

Figure 4: *Prolific production of* Chalara fraxinea (Hymenoscyphus pseudoalbidus) *apothecia on ash leaf litter.*

in late October 2012 with the first cases in Northern Ireland a few weeks later. Up to the end of July 2013 there had been 87 cases in the Republic of Ireland, including 36, in plantations in Counties Carlow, Cavan, Clare, Galway, Kildare, Kilkenny, Leitrim, Longford, Meath, Tipperary and Waterford; 19 in nurseries and garden centers, 14 in roadside plantings and 14 in farm plantings. At the same point in time (July 2013), in N. Ireland 88 premises have been confirmed positive for the fungus *Chalara fraxinea*. Eighty five of these were recently planted sites in Counties Antrim, Armagh, Derry, Down, and Tyrone, with an additional three findings in nursery/retail/trade situations.

On the island of Ireland the vast majority of ash dieback outbreaks have been identified as part of a trace-forward exercise from batches of plants originating from a source known to be infected. Almost all were planted within the past five years.

In Sweden the disease was first observed in southernmost regions of the country in 2002 (Figure 5). Within the past 10 years it has spread to virtually the entire Swedish ash population resulting in almost total death of the ash population (Barklund 2005, 2006). However there is evidence that a very small proportion of ash trees demonstrated a level of resistance, or at least reduced susceptibility to the

Figure 5: *Mature ash tree (in Sweden) infected with* Chalara fraxinea *with severe shoot dieback.*

pathogen. Stener (2012) assessed and analysed the clonal differences in susceptibility of *Fraxinus excelsor* to *Chalara fraxinea* in southern Sweden. He examined 106+ trees from 27 stands, based on their phenotypes. Although none of the clones seemed to be totally resistant, some were less susceptible and remained resistant after six years despite heavy inoculum pressure. Stener (2012) concluded that, given the high heritability of resistance, strong age × age correlations and weak genotype × environment interactions, there was good scope for breeding less susceptible trees for the future. Current Forestry Commission UK trials comprising seed from 15 different sources, including from Britain, Ireland, France and Germany are underway in eastern Britain

A rapid PRA has been conducted to assess the threat of ash dieback to the UK (Webber and Hendry 2012). This PRA concluded:

- The spores are unlikely to survive for more than a few days.
- Spore dispersal on the wind is possible from mainland Europe.
- Trees need a high dose of spores to become infected.
- The spores are produced from infected dead leaves during the months of June to September.
- There is a low probability of dispersal on clothing or animals and birds;
- The disease will attack any species of ash.
- The disease becomes obvious in trees within months rather than years of infection.
- Wood products would not spread the disease if treated properly.
- Once infected, trees can't be cured.
- Not all trees die of the infection, some are likely to have genetic resistance.

Pseudomonas syringae pv. aesculi (horse chestnut bleeding cankers)

Bleeding cankers on horse chestnut (*Aesculus hippocastanum* L.) have been observed in the UK for many years. In the 1970s, Brasier and Strouts (1976) reported bleeding on branches and trunks of horse chestnut. The causal organisms were identified as two species of *Phytophthora*, *P. cactorum* (Leb. and Cohn) Schroet. and *P. citricola* Sawada sensu Waterhouse. Until a few years ago bleeding cankers on horse chestnut were quite rare. However, in the past decade there has been increasing incidences in the UK, Netherlands, Belgium and Germany of bleeding cankers.

The early symptom of infection is the appearance of bleeding lesions, producing a gummy ooze. These bleeding cankers can develop on the main trunk close to soil level or can start higher up and extend upwards. In the spring the ooze is dark but transparent, as the season progresses the bleeding from cankers increases with dark rusty-brown droplets running down the trunk of the tree. Further inspection around the lesions and under the outer bark will reveal an inner bark or cambium which is a dark brown, instead of the normal white-cream colour. As the infection progresses and the patches of dead cambium coalesce around the entire girth of the stem, signs of disease may be obvious in the crown. Typically this may be observed as yellowing of the foliage, premature leaf fall and possibly death in severe cases of the disease.

The organism associated with this most recent outbreak of bleeding cankers has not been *Phytophthora* spp. but has been identified as the gram –ve bacterium *Pseudomonas syringae pv. aesculi* (Webber et al. 2008, Steele et al. 2010). Over time cankers often become colonised with other wood rotting pathogens, e.g. *Armillaria mellea*, thus confounding attempts to identify the causal agent.

The first report of *P. syringae* pv *aesculi* in Ireland was in 2010 (EPPO, 2010). The pathogen was detected on horse chestnut trees growing in Phoenix Park in Dublin where horse chestnut account for approximately 9% of tree cover – 1,800 trees. In order to prevent the spread of the bacterium, the initial reaction to the diagnosis of the disease was the removal and burial of infected trees. There is some evidence that some infections can stabilize, so immediate removal may not be the best option. An extensive survey of the remaining trees was undertaken and resulted in the removal of around 30 diseased trees (OPW, 2010). *P. syringae* pv *aesculi* has also been found in the Botanical Gardens, Glasnevin, Dublin where mature trees have been lost every year (Dr. Matthew Jebb, Director of the National Botanic Gardens, Dublin; Personal Communication). Horse chestnut bleeding cankers have also been observed on horse chestnut trees in several parks and estates in Northern Ireland.

A Forestry Commission survey of horse chestnut trees in Great Britain in 2007 (Anon. 2008b) found the disease widespread, with 49% of all tree examined showing some sign of infection. This could represent 35,000 to 50,000 trees. In some parts of England over 85% of trees were infected (e.g. west Midlands). Trees ranging from saplings to large mature amenity trees were affected. In some cases they were important features in historic gardens or avenues.

Dothistroma septosporum (Mycosphaerella pini or Scirrhia pini) (red band needle blight)

Red band needle blight or Dothistroma needle blight is a serious disease of certain pines caused by the ascomycete fungus *Dothistroma septosporium* (anamorph *Microsphaerella pini*). Until recently the disease was only found on Monterey pine (*Pinus radiata* D.Don) in the southern hemisphere. At least 86 *Pinus* species, 5 *Picea* species, European larch (*Larix decidua* Mill.) and Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) have been reported as hosts of the disease (Watt et al. 2009). It is now found widely in the British Isles on Corsican pine (*Pinus nigra* Arnold ssp. *laricio*), lodgepole pine (*Pinus contorta* ex Louden var. *latifolia*) and Scots pine (*P. sylvestris* L.). Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Norway spruce (*P. abies* L.) Karst.), European larch and Douglas fir have all been reported as being susceptible, although probably with a low level of susceptibility. Trees of all ages can become infected. The symptoms are most obvious in July and August and are first observed at the base of the crown on older needles, with infected needles developing yellow and tan spots and bands that turn red (Brown and Webber 2008). The fruiting bodies, acervuli, are formed in the red bands. Conidia are exuded in white to pale pink mucilaginous masses during misty or damp weather and are disseminated in water droplets both within and between trees. Severe needle blight is likely to occur following period of damp weather and temperatures of

15–20 ^{o}C, conditions commonly found in Ireland in spring and summer. *D. septosporium* can also produce sexually formed spores if both mating types are present. There is evidence that both mating types are indeed found in Great Britain (Groenewald et al. 2007).

By 2006 in Great Britain, 70% of Corsican pine stands under the age of 30 years were infected with red band needle blight. This represented an area of at least 6,245 ha. By 2008, the disease had started to impact on lodgepole pine with 850 ha affected (Webber 2011).

The risk to plant health posed by *D. septosporium* to the EU has been evaluated by the European Food safety Authority (Anon. 2013b), and significant loss to timber production, in particular Monterey pine through growth reduction due to needle loss, is expected. The European and Mediterranean Plant Protection Organisation (EPPO) recommend that planting material should come from an area free of the pathogen and in addition that the place of production should have been found free. Great Britain has produced a *Dothistroma* control strategy (Anon 2012b), and trials are currently planned in Monaughty Forest, Moray, Scotland to use aerial application of a selective fungicide to combat this disease. This will be the first aerial application of a fungicide in a British forest. Red band needle has been found on Corsican pine (*Pinus nigra* var. *maritima* (Ait.) Melville) trees and Scots pine trees in Northern Ireland, but has not been reported in southern Ireland (O'Neill 2011).

Insect and nematode pests

Although this review has concentrated most heavily on fungal and bacterial diseases, there are also several serious insect pests that threaten the wellbeing of Irish trees and woody crops. Some of these have already been found or become established in parts of Great Britain where they are causing significant damage. The most important invertebrate organisms that pose the greatest threat to Irish forests are reviewed below.

Thaumetopoea processionea (oak processionary moth)

The oak processionary moth has caused defoliation of oak in many European countries. The foliage of many species of oaks, including English (*Quercus robur* L.), sessile (*Q. petraea* (Mattuschka) Liebl.) and Turkey oaks (*Q. cerris* L.*)* are susceptible to damage from the feeding of larvae (caterpillars; Figure 6a). Hornbeam (*Carpinus betulus,* hazel (*Corylus avellana* L.), beech, sweet chestnut (*Castanea sativa* Mill.) and birch (*Betula nigra* L.) have also been reported damaged, although mainly when associated with areas of badly defoliated oaks.

Oak processionary moth is also a risk to human health. The caterpillars are covered in hairs that contain a toxin which causes a severe skin irritation, conjunctivitis or, when inhaled, can cause an allergic reaction in humans. These problems are quite significant as oak processionary moth is often most abundant on urban trees, along forest edges and in amenity woodlands.

Oak processionary moth is a native species of central and southern Europe, where it is widely distributed. However, in recent years its range has expanded northwards to northern France and the Netherlands. Recently large colonies of the pest have been found in London, England which, at the time of writing (August 2013), is the only place where it has been found in Britain and Ireland. Further details about the oak processionary moth can be found on the Forestry Commission website (Anon. 2013c).

Thaumetopoea pityocampa (pine processionary moth)
This pest is not established in the UK or Ireland. However, it has been moving northwards across Europe. There was a single transient population of larvae (caterpillars) found in a UK nursery in 1995 on Scots pine plants, which had been imported from Italy the previous year. The affected trees and soil were treated, and subsequent monitoring did not detect the pest. An adult was caught in a light trap in Berkshire in 1966, but the origin of that moth was not traced. Details of the pest and its diagnosis are given in the EPPO protocols (Anon. 2004).

Cameraria ohridella (horse chestnut leaf miner)
Horse chestnut leaf miner was first identified in the UK in Wimbledon, London in 2002. It is a moth which produces small caterpillars that feed inside the leaves, causing brown or white blotch mines to develop between the leaf veins (Figure 6b). The first signs of infection usually appear in June, with elongated blotches in the leaf first appearing white but soon turning brown. The caterpillars or pupal cocoons develop within the mined areas. By late August the whole leaf may have been colonised and have turned brown. These heavily infected leaves are dropped prematurely. Infected trees will usually flush normally the following spring. Further details about Horse chestnut leaf miner can be found on the Forestry Commission Pest Alert (Tilbury and Evans 2003).

Anoplophora glabripennis (Asian longhorn beetle)
Asian longhorn beetle is a native of China (Figure 6c). It has the potential to cause very serious damage to broadleaf trees and has had a major impact on trees in the USA and Italy. In March 2012, a breeding population of Asian longhorn beetle was found in Paddock Wood, close to Maidstone in Kent. The Forestry Commission (Anon. 2013d) reported that 65 trees were found to be infested and over 100 live larvae had been recovered from tree samples taken within the infestation zone. Over 2,000 trees were removed and destroyed and a 2 km buffer zone was set up around the infected area.

The adult beetle is very distinctive. Adult beetles are large (about 20–40 mm long) and shiny black with variable white markings. Particularly distinctive are their antennae, which are longer than their bodies (up to twice the body length) and are black with white or light blue bands. The most obvious symptoms of Asian longhorn beetle damage are the circular exit holes made by the emerging adult beetles in the trunks and branches, which are about 10 mm in diameter and are usually found in the main trunk. Further details about the pest are given in the EPPO data sheet (Anon. 1999).

Bursaphelenchus xylophilus (pine wilt nematode)
The pine wilt nematode (Figure 6d), *Bursaphelenchus xylophilus* has been causing widespread losses to pines in Japan since the early 1900s. Pine wilt nematode is currently regarded as a major threat to European forests. It has become established in Portugal and despite the application of stringent measures, the pest has continued to spread and kill large numbers of pine trees. The nematode is vectored by beetles in the genus *Monochamus* which transmit nematodes to either living trees (maturation feeding) or dying/dead trees (oviposition). Details of the pathogen are given in the Iowa State University Extension Plant Pathology (Gleason et al. 2000). EPPO's recommendations to prevent the introduction of *B. xylophilus* and its vectors cover plants and wood of conifers from countries where the nematode occurs. It is recommended that importation of coniferous plants should be prohibited, but that countries may choose whether to prohibit the importation of wood. If not prohibited,

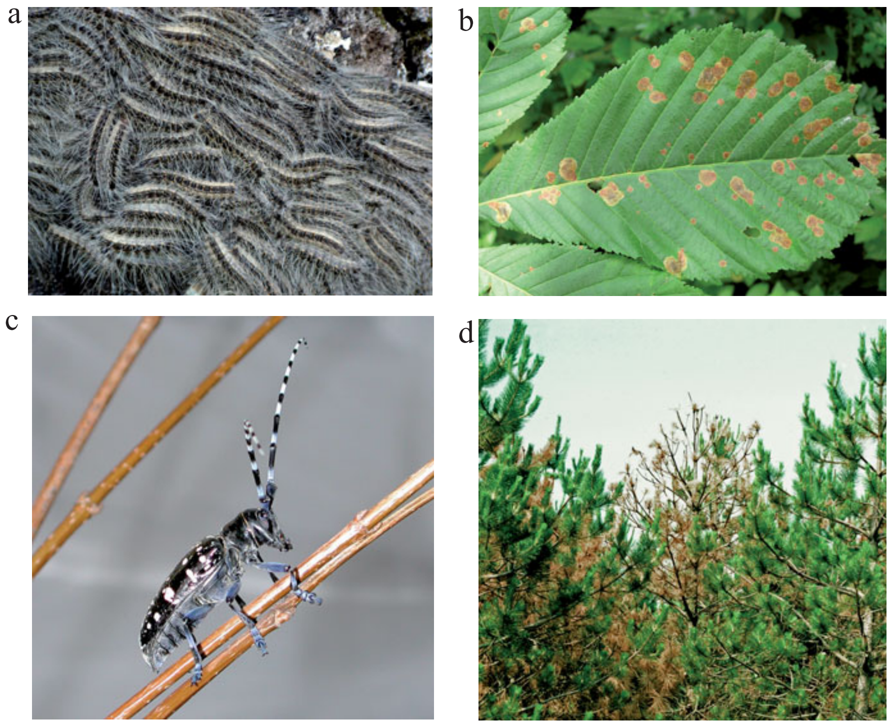

Figure 6: *Images of forest insect pests and the damage caused by them:*
a) *Oak processionary moth larvae* (Thaumetopoea processionea). *Photographer: Melody Keena, USDA Forest Service, Bugwood.org.*
b) *Horse chestnut leaf miner* (Cameraria ohridella). *Photographer: Milan Zubrik, Forest Research Institute Slovakia, Bugwood.org.*
c) *Asian longhorn beetle* (Anoplophora glabripennis). *Photographer: Haruta Ovidiu, University of Oradea, Bugwood.org.*
d) *Damage caused by pine wilt nematode* (Brusaphalenchus xylophilis). *Photographer: Anon, USDA Forest Service, North Central Research Station Archive, Bugwood.org.*

wood must have been heat treated to a core temperature of 56 °C for 30 minutes. In the case of packing wood (crates, dunnage etc.), kiln drying could be accepted instead, whereas for particle wood, the alternative of fumigation is also acceptable (OEPP/EPPO 1986). Where the pathogen is established there has been some success from the use of biological control including the endoparasitic fungus *Esteya vermicola* (Wang et al. 2011).

Plant health legislation and control measures

The International Plant Protection Convention (IPPC) is an international agreement that has the objective to protect cultivated and wild plants by preventing the introduction and spread of pests. The EU (including UK and Ireland) are among the 177 signatories to the Convention. The responsibility to deliver the aims of IPPC lies with the regional plant protection organizations. In Europe, EPPO represents 50 member countries, which includes almost every country in the European and Mediterranean region. The specific aims of EPPO are:

- to protect plant health in agriculture, forestry and the uncultivated environment;
- to develop an international strategy against the introduction and spread of pests (including invasive alien plants) that damage cultivated and wild plants, in natural and agricultural ecosystems;
- to encourage harmonisation of phytosanitary regulations and all other areas of official plant protection action;
- to promote the use of modern, safe, and effective pest control methods;
- to provide a documentation service on plant protection.

Within the European Union, the Directorate General (DG) for Health and Consumers (DG SANCO) has responsibility for Plant Health (not DG Agriculture or DG Environment). The legislation is designed to underpin the operation of the Single European Market and the global trade in plants and plant products. The Council of Ministers has decided on the legal requirements for trade that are needed to protect crops, fruit, vegetables, flowers and forests from harmful pests and diseases that do not exist or are not widespread in the EU. Member States are required to enact in domestic legislation the procedural requirements of the Plant Health Directive (2000/29/EC).

The European Commission has been reviewing the plant health regime for some years and it is likely that a new EU Plant Health Directive will be developed in relatively near future. In an initial evaluation, the increased risk arising from globalisation of trade and travel was clearly identified. It was concluded that the main problems with the current regime include:

- insufficient focus on prevention in relation to increased imports of high risk commodities;
- a need for prioritising harmful organisms at EU level across all Member States;
- a need for better measures for controlling the presence and natural spread of harmful organisms which manage to enter the EU territory;

- a need for modernising and upgrading the measures concerning the phytosanitary control of intra-EU movements (plant passports and protected zones).

It is essential that there are clear plant health strategies and policies at international, national and local levels. Once a non-indigenous pathogen or pest is introduced into a new area, it can potentially become rapidly established and cause untold damage and may be impossible to eradicate. Pests and pathogens do not stop at borders and it frequently requires close co-operation between neighbouring member states or jurisdictions. One good example of this has been the development of the All-Ireland Chalara-Disease-Control Strategy, which has been a collaboration between the respective Government Departments and Forest Services in the North and the Republic of Ireland.

Possible reasons for recent increased incidences of new plant diseases

In the past decade at least seven new microbial pathogens have been detected on the island of Ireland: *Phytophthora ramorum*, *P. lateralis*, *P. kernoviae*, *P. pseudosyringae*, *Chalara fraxinea, Mycosphaerella pini* and *Pseudomonas syringae pv. aesculi*. This trend has been observed in many other European countries. At least three contributory factors contribute to this trend.

Increased global movement of plants

In recent years there has been a huge increase in the rapid, global movement of plants and plant parts. Large container ships and aircraft can be used to move plants from one part of the world to another in just a few days. Often these plants are coming from Far East countries where the pathogen may not have been a problem in its natural surroundings. However, when introduced into a new environment it may become established quickly and cause significant damage.

The plant health authorities in both Northern and the Republic of Ireland have a major challenge in ensuring that the current plant health legislation is met. Brasier (2008) highlights the biosecurity threat to the UK and global environment from international trade in plants. Brasier (2008) states, "biosecurity protocols have been overtaken by events – primarily global shifts in market structure and practice and by developments in scientific knowledge – and are now outmoded, flawed, institutionalized, and too ineffectual."

The basis of the European Union open market is that there should be no barriers to trade. It can often be a difficult balance to reach between these two competing pressures i.e. free trade and effective plant health protection. Usually action can only be taken if there is strong scientific evidence, e.g. in the form of a PRA to justify taking action which will restrict the movement of plants or other goods.

Global warming

Even a small change in temperature may tip the balance in favour of a pathogen or pest. The warmer climate has meant that many of the recent introductions, particularly of pests to the south-eastern corner of England, have resulted in viable colonies becoming established. Previously, even a decade ago, this would probably not have happened as the cooler winter temperatures would have prevented their survival. While a rise in mean temperature may not be a major factor in Ireland, wetter summers as predicted by climate models could be very advantageous to many pathogens. Also the increased frequency of severe weather events may put plants and especially trees under undue stress, making them more susceptible to pest or disease attack.

Lack of public understanding

Frequently, the general public do not have a good understanding of the issues of plant health. To a greater extent they are aware of animal health issues but do not always take the same consideration for plant health. The recent publicity surrounding ash dieback has brought plant health and plant diseases to their attention, many for the first time.

Actions to address the current situation

The challenges are great if Ireland’s high plant health status is to be maintained. As an island off the north-west corner of Europe we should have some advantages over other European countries. Britain can often act as an “early warning” system as the appearance of a new pest or disease there can indicate that Ireland can expect it to arrive as well within a short time. It is very important that when land owners and foresters are planting new forests, they understand the importance of introducing species diversity. Haas et al. (2011) studied the effect of tree species diversity on the incidence of *P. ramorum*. In spite of the wide host range of the pathogen they found evidence of pathogen dilution whereby disease risk was lower in sites with higher species diversity. They concluded that, although nearly all the plants in the ecosystem were *P. ramorum* hosts, alternative hosts diluted disease transmission by competent hosts, thereby buffering forest health from infectious disease.

The main action to address issues surrounding plant health is to work to increase public awareness of the threats to Ireland’s trees posed by introduced pests and pathogens. There is an urgent need to make members of the public more aware of the dangers of plant diseases and their potential to result in devastating changes in the environment. Scientists, foresters, horticulturalists, and all those involved in growing/managing plants, should take every opportunity to educate the public on the dangers of importing unauthorised plants and plant parts into the country, when for example returning from holidays abroad. Awareness campaigns could help to keep people informed about the importance of trees to the environment and to society, and highlight that any loss is very serious. Ireland is one of the least forested countries in Europe (11% compared to Finland (>70%), Norway (>30%) or even France (29%)) and consequently we cannot afford to endanger our forests.

It is important that everyone, both professional and amateur plant and tree enthusiasts, understand that if they suspect the presence of any non-indigenous pest or pathogen, they have a statutory responsibility to report its presence immediately to the appropriate plant health authority. In Ireland the contact details can be obtained from the Department of Agriculture, Food and the Marine (Republic of Ireland) or the Department of Agriculture and Rural Development (Northern

Ireland), whose web addresses are given at the end of this article in Appendix 1.

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Appendix 1

The following websites give important additional information about most of the diseases mentioned in this review, plus many others, with detailed descriptions of symptoms, distribution, importance, control strategies and high quality photographs, etc.

Agri-Food and Biosciences Institute (Northern Ireland)
http://www.afbini.gov.uk

Coillte (Ireland)
http://www.coillte.ie/

Department of Agriculture and Rural Development (Northern Ireland)
http://www.dardni.gov.uk/index/fisheries-farming-and-food/plant-health-for-northern-ireland.htm

European and Mediterranean Plant Health Organisation (EPPO)
http://www.eppo.int

Food and Environment Research Agency (UK)
http://www.fera.defra.gov.uk/plants/plantHealth/

Great Britain Forestry Commission (Great Britain)
http://www.forestry.gov.uk/pestsanddiseases

Department of Agriculture, Food and the Marine (Republic of Ireland)
http://www.agriculture.gov.ie/forestservice/

United States Department of Agriculture (United States of America)
http://www.aphis.usda.gov/plant_health/index.shtml

The potential economic returns of converting agricultural land to forestry: an analysis of system and soil effects from 1995 to 2009

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Abstract
Private land owners have been responsible for the majority of annual afforestation in Ireland since the mid-1990s, but planting rates have generally been declining since 2002. Although the decision to plant may be driven by a number of factors, the profitability of forestry as a land-use option should be an important driver and offer some insight into trends in afforestation rates. As farmers undertake most afforestation in Ireland it is important to account for the opportunity cost of lost agricultural income when analysing the financial outcome of planting. In addition, soil quality plays an essential role in dictating the productivity and profitability of both agriculture and forestry. This study examines the effects of soil quality and superseded agricultural system on the potential profitability of afforestation by farmers between 1995 and 2009. Data from the National Farm Survey were employed to identify the annual gross margins for six agricultural systems on six soil types that differ in terms of quality. The measures of soil quality were translated into potential yield classes for forestry using an existing productivity model and Teagasc's Forest Investment and Valuation Estimator was employed to calculate the net present value of afforestation for each of the systems and soil types. The results demonstrate how the competitiveness of forestry as a land-use option is influenced by soil quality and superseded enterprise and how forestry has become more competitive with agricultural enterprises over the period of analysis.

Keywords: *Afforestation, net present value, opportunity cost, soil quality.*

Introduction

The development of Irish afforestation policy has focused on soil quality to a large degree. State afforestation during the 20th Century was generally limited to lower quality marginal and sub-marginal soils to avoid competition with agriculture (OCarroll 2004). Afforestation of private land was limited for most of the century, although some form of financial support was available. However, with the introduction of annual payments to offset the loss of income during forest establishment private landowners began to show more interest in planting forests. Farmers undertook over 80% of all afforestation in Ireland between 1995 and 2009 and they are likely to continue to be the main planters of forests given the decline of public planting and the maintenance of higher premium payments for farmers

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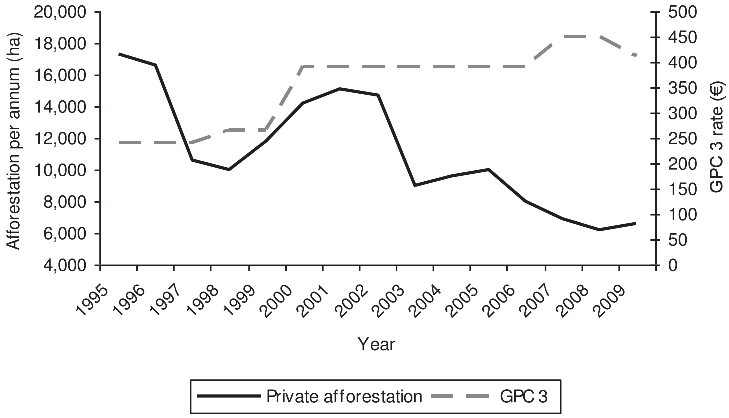

Figure 1: *Private afforestation levels and the Grant/Premium Category (GPC) 3 rate between 1995 and 2009 in Ireland.*

compared to other private planters. Greater emphasis has been placed in recent years on the environmental outcomes of afforestation and restrictions have been placed on planting on unenclosed land and in environmentally sensitive areas. This combination of factors suggests that the establishment of forests on improved agricultural land by farmers will continue to be central to afforestation policy in Ireland. Thus, competition between agriculture and forestry, particularly in terms of enterprise and land quality, is of particular relevance to current policies and the development of future policies. Since the early 1990s, farmers have been able to avail of grants that cover the full cost of planting and annual premiums to offset the loss of agricultural income during forest development. Although funding has been increased on a number of occasions, afforestation rates have been generally declining since 2002 (Figure 1).

It is well recognised that the characteristics of farm and farmer can have a significant impact on the decision to plant forests (Collier et al. 2002, Howley et al. 2012), but the financial outcome of planting should still play an important role in this process. Previous examinations of the economics of forestry in Ireland have revealed the importance of state supports for forestry and competing agricultural policies in explaining variations in afforestation rates (McCarthy et al. 2003). Behan and McQuinn (2005) modelled a panel dataset of afforestation between 1986 and 2001 across five regions in Ireland and found that the relative rate of return between forestry and agriculture had a significant and positive effect on planting rates. However, McCarthy et al. (2003) found that agricultural gross margin itself did not explain afforestation trends at the county level. Breen et al. (2010) demonstrated how forestry can compete financially with other land uses by calculating the net present value (NPV) of moving from a range of agricultural enterprises to Sitka spruce (*Picea sitchensis* (Bong.) Carr.), ash (*Fraxinus excelsior* L.) or mixed forestry. The study focused on less profitable agricultural enterprises as these were deemed to be the most likely to be superseded and found that replacing store to finished-beef with Sitka spruce resulted in the greatest NPV. Such results help to explain why cattle and other livestock farmers have been seen to be more likely to enter forestry (Ryan et al. 2008, Howley et al. 2012).

One of the fundamental factors in any land-use decision is soil quality. This factor dictates what enterprise can be engaged in and how productive it will be. Forestry is recognised as a robust land-use option that is less restricted than agriculture by poor site conditions. The fact that much of Ireland's forests exist on poorer quality sites is a result, in part, of both state policy and landowner decision making. Although agricultural enterprise may be a reflection of soil quality, a more detailed examination of the role of soil type in the financial implications of land conversion to forestry is warranted. In addition, examining the relative changes in the profitability of forestry over time may offer an insight into afforestation rates and patterns. This study examines how the NPV of converting agricultural land to forestry has been affected over time by changes in the opportunity cost of agricultural systems on different soil types. Data were derived from the National Farm Survey (NFS), which collects detailed information from a representative sample of farms in Ireland, including a six-category soil quality variable. This variable was converted to yield class estimates to reflect a more realistic financial outcome of afforestation. The impact of converting land from four agricultural systems to commercial forestry between 1995 and 2009 was analysed using the Teagasc Forest Investment and Valuation Estimator (FIVE).

Methods

The National Farm Survey

The NFS is Ireland's contribution to the EU Farm Accountancy Data Network (FADN) and collects detailed information from a representative sample of farms in Ireland. Data from approximately 1,200 farms are collected each year and farm systems are classified by enterprises defined in Commission Decision 78/463 and its subsequent amendments. These categories have changed over time. Table 1 gives examples of enterprises that would generally be included in the systems. Two

Table 1: *Enterprises included in NFS systems used in Ireland.*

System	Enterprise examples
Dairy	Specialist milk production
Tillage	Specialist cereals, oilseeds and protein crops, Field crops combined with non-dairying grazing livestock, Specialist root crops, Various field crops combined
Cattle	Specialist cattle - mainly rearing
Sheep	Specialist sheep, sheep and cattle combined

additional categories, Dairy Other and Cattle Other, were included in the original analysis but are not reported as they contain a diverse variety of enterprises.

Gross margin (GM) is a measure of agricultural profitability generated from the NFS data and is defined as gross outputs minus direct costs, such as outlays on fertilisers and feed stuffs. In addition to economic measures, the physical characteristics of farms are collected in the survey, including a six-level measure of soil quality defined primarily by the diversity of uses for which land can be utilised. Average GMs for each type of soil were derived for the four agricultural systems for each year between 1995 and 2009, where data were available. The GM values used in the calculations are net of subsidies. Farmers can currently plant most of their land and retain their single farm payment, but previous to decoupling converting to forestry may have resulted in the loss of some financial support. This is an important limitation of the study, as in some circumstances the loss of supports may have amounted to a significant cost.

Forest Investment Valuation Estimator

A discounted cash flow approach was adopted to generate the net present value (NPV) of converting a hectare of different soil categories from six agricultural systems to forestry. The standard formula for NPV is:

$$NPV = \frac{\sum_{t=0}^{T} R_t - C_t}{(1+i)^t} \quad (1)$$

Where R represents revenues, C represents costs, t is the relevant year and i is the discount rate. For this analysis it was assumed that a combination of 80% Sitka spruce and 20% Japanese larch (Larix kaempferi (Lamb.) Carr.), which represents a common composition over the period of analysis, was established. The Teagasc Forest Investment Valuation Estimator (FIVE) was employed to calculate the NPVs (see Breen et al. (2010) for more details of the FIVE). This Excel-based tool employs the UK Forestry Commission yield models (Edwards and Christie 1981) to predict future timber outputs based on species, yield class, rotation and thinning regime. Timber outputs, from thinnings and clearfell, were valued using 10-year average conifer roundwood prices reported by Coillte and adjusted to the relevant year using the consumer price index (CPI). Thus it is assumed that timber prices did not change over the period of analysis in real terms. Costs of inspection paths, insurance and reforestation were included in the calculation and it was assumed that all afforestation costs would be covered by the available grant. The relevant farmer premium rate (Grant/Premium Category 3) available in the given year was employed in all calculations and included for the first 20 years of the rotation. Before 2000, payments were specific to the agriculturally disadvantage status of an area and the payment associated with the most severely disadvantaged areas was included for this period. Financially optimum rotations were used for each yield

Table 2: *Soil categories and expected yield classes for various land-category types in Ireland.*

Soil Category	Limitations of Soil	Expected Yield Class ($m^3\ ha^{-1}\ yr^{-1}$)
1 Wide	No limitations	24
2 Moderately wide	Minor limitations	24
3 Somewhat limited	Higher elevations, heavier, poorer structure	20
4 Limited	Poor drainage	20
5 Very limited	Agricultural potential greatly restricted	18
6 Extremely limited	Mountainous, steep slopes, shallow soil	14

class and varied between 38 and 44 years. A percentage of revenue from thinnings and clearfell was subtracted to cover the costs of timber sales.

Soil quality affects both agricultural and forest productivity. To ensure a realistic reflection of land conversion, the NFS soil categories were translated into forest yield class estimates based on the soil productivity models for Sitka spruce in Ireland described in Farrelly et al. (2011). Table 2 outlines the categories and identifies the estimates of the associated yield class that may be achievable on such sites. The soil and system specific GMs were incorporated into the NPV calculations as an annual cost to account for the opportunity cost associated with converting land to forestry. Thus, soil type is reflected in both the opportunity cost of the agricultural income foregone and the productivity of the forest. The NFS sample is representative of farms at the level of system and size but not soil type. Thus, although the GMs are valid for the farms included in the sample, they are not representative of all farms in Ireland.

Results

Tables 3 to 6 display the soil category (SC) specific NPVs per year for converting 1 ha of land from agriculture to forestry, with the associated sample size in brackets. Values that are derived from particularly small samples ($n \leq 3$) are highlighted with asterisks. This is of particular note with the lowest soil category, 6 or Extremely limited, which includes very few farms and the associated NPVs should be treated with particular caution. As timber prices are assumed not to change in real terms over time, the temporal variability in the figures stems primarily from changes to the premium rate and the profitability of agriculture. The sample sizes reflect the demands that different agricultural systems have for land quality with a higher proportion of dairy and tillage farms occurring on better quality soils.

There is significant variability between systems but forestry does not appear to compete with Dairy under any conditions for the average farm values included in the sample. It is interesting to note the significant diversity in the tillage figures but in general the results would suggest that forestry has not been competitive with tillage, at least on soils of reasonable quality, over the time period. The NPVs for

Table 3: *Soil category (SC) and yield class (YC) specific NPVs (€ ha^{-1}) for forestry replacing a dairy system in Ireland. Sample sizes are included in brackets. The soil categories are defined in Table 2.*

Year	SC1 / YC24	SC2 / YC24	SC3 / YC20	SC4 / YC20	SC5 / YC18	SC6 / YC14
1995	−18,139 (90)	−22,533 (38)	−17,592 (51)	−13,916 (53)	−7,797 (20)	−22,996* (1)
1996	−18,332 (91)	−81,595 (37)	−16,202 (61)	−13,530 (66)	−8,961 (22)	−24,405* (1)
1997	−16,788 (109)	−19,554 (27)	−15,419 (57)	−13,245 (81)	−8,909 (21)	–
1998	−15,623 (112)	−17,013 (26)	−14,271 (49)	−12,341 (74)	−7,294 (18)	−4,090* (1)
1999	−15,777 (110)	−14,087 (26)	−14,811 (51)	−11,900 (81)	−5,828 (18)	−2,546* (1)
2000	−17,391 (142)	−15,365 (25)	−15,107 (56)	−12,301 (84)	−8,667 (23)	−5,060* (1)
2001	−19,945 (156)	−22,022 (42)	−16,558 (57)	−14,700 (96)	−10,724 (27)	−6,282* (1)
2002	−15,288 (143)	−16,823 (31)	−13,710 (51)	−8,800 (79)	−5,723 (26)	−2,420* (1)
2003	−14,933 (151)	−17,733 (42)	−15,599 (49)	−12,886 (82)	−8,715 (28)	−3,484* (1)
2004	−17,649 (140)	−16,860 (42)	−16,426 (47)	−14,947 (78)	−8,812 (26)	−6,211* (1)
2005	−15,785 (141)	−15,471 (36)	−14,662 (44)	−11,537 (75)	−7,922 (27)	−542* (1)
2006	−12,249 (139)	−15,923 (34)	−13,486 (43)	−10,558 (69)	−6,139 (26)	–
2007	−19,048 (138)	−23,132 (31)	−21,206 (40)	−15,556 (65)	−10,017 (21)	–
2008	−18,500 (127)	−18,881 (31)	−16,660 (36)	−10,774 (57)	−5,957 (17)	–
2009	−6,575 (120)	−8,216 (27)	−6,313 (36)	−2,150 (56)	−1,618 (14)	–

*Very small sample size ($n \leq 3$)

forestry replacing cattle and sheep enterprises, however, suggest that forestry may be a highly competitive alternative land-use option.

The results also suggest that soil category has a significant effect on NPVs within systems. The effects of annual variation in the agricultural gross margins can be removed by calculating the average NPV per soil category and enterprise over the time period, with the original figures adjusted using the consumer price index

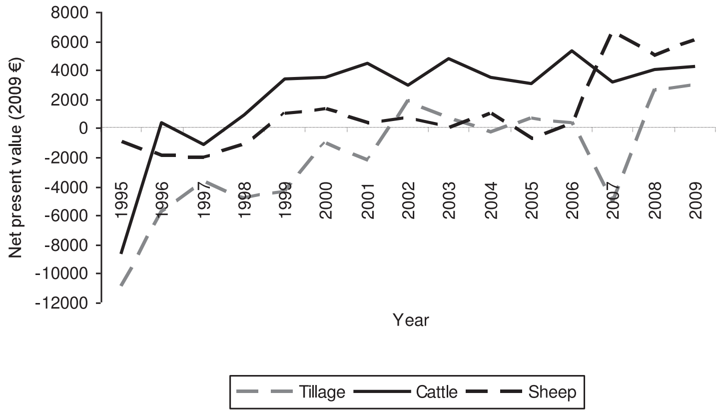

Figure 2: *Adjusted NPVs (expressed in 2009 equivalents) for forestry replacing tillage, cattle and sheep systems on soil category 1 for the period 1995 to 2009.*

(CPI) and expressed in 2009 equivalents (Table 7). These figures show a distinctive trend in increasing forestry profitability on lower quality soils.

In addition to the effects of soil and system, the results suggest that forestry has become more competitive over the time period although as values are expressed in the relevant year the total effect may be confounded by inflation. Figure 2 displays the NPVs for cattle, sheep and tillage systems on soil category 1 (SC1) expressed in 2009 prices. By adjusting the values using the CPI, the values are more comparable and show a general, although not consistent, positive trend in the profitability of forestry over time on this soil type. For brevity only the values for SC1 are included, but similar increases over time are evident for other soil categories and for the Dairy system, although the NPV of the latter is never positive.

Discussion

The results of this study offer a realistic financial analysis of the conversion of land use from a range of agricultural systems to forestry, taking account of the effects of soil quality on productivity. Based on the farms in the NFS, the results suggest that forestry is unlikely to compete financially with dairy systems under any circumstances. This is unsurprising given the profitability of the system and the fact that it is concentrated on better quality soils. The results for replacing tillage land are more inconsistent and are likely to be heavily influenced by variability in yield (e.g. impact of weather conditions) and direct costs. In general, farms in this study that are engaged in cattle and sheep enterprises would benefit financially from converting land to forestry. This finding is consistent with other Irish studies, which concluded that farmers engaged in livestock enterprises are the most likely to benefit financially from converting land to forestry (Breen et al. 2010) and are more likely to have planted previously (Howley et al. 2012).

The influence of soil quality on the profitability of planting was identified with a distinctive trend of NPVs increasing as soil quality decreased (Table 7). This can

Table 4: *Soil category (SC) and yield class (YC) specific NPVs (€ ha^{-1}) for forestry replacing a tillage system with positive values in bold. Sample sizes are included in brackets. The soil categories are defined in Table 2.*

Year	SC1 / YC24	SC2 / YC24	SC3 / YC20	SC4 / YC20	SC5 / YC18	SC6 / YC14
1995	−7,451	−7,439	−8,466	−4,620	2,444*	–
	(54)	(35)	(11)	(2)	(1)	
1996	−4,040	−4,457	−6,865	−1,866	−3,971*	–
	(51)	(36)	(12)	(2)	(2)	
1997	−2,616	−4,510	−8,468	−1,621	**1,802***	–
	(50)	(43)	(9)	(2)	**(1)**	
1998	−3,466	−6,438	−7,364	−2,795	**2,404***	–
	(50)	(35)	(11)	(2)	**(1)**	
1999	−3,211	−4,377	−3,019	**279**	**3,596***	–
	(34)	(31)	(9)	**(2)**	**(1)**	
2000	−831	−8,036	−11,230	**424**	**4,646***	–
	(44)	(33)	(8)	**(2)**	**(1)**	
2001	−1,799	−7,549	−679	−29	**3,222***	–
	(48)	(37)	(8)	(2)	**(2)**	
2002	**1,549**	−2,057	−708	**1,676**	**5***	–
	(54)	(40)	(12)	**(2)**	**(1)**	
2003	**600**	−2,266	−2,254	**3,009**	–	–
	(62)	(38)	(9)	**(3)**		
2004	−300	−2,319	−2,285	**934**	–	–
	(67)	(36)	(10)	**(4)**		
2005	**641**	−3,214	−1,742	**1,424**	–	–
	(52)	(27)	(8)	**(3)**		
2006	**312**	−4,138	−5,217	**2,259**	–	–
	(50)	(24)	(8)	**(2)**		
2007	−5,175	−6,344	−4,099	**274**	–	–
	(59)	(26)	(10)	**(1)**		
2008	**2,699**	−2,029	**360**	**5,709**	–	–
	(59)	(29)	**(12)**	**(2)**		
2009	**2,928**	**832**	**2,596**	**6,970**	–	–
	(48)	**(25)**	**(11)**	**(2)**		

*Very small sample size ($n \leq 3$)

likely be attributed to the robustness of forestry as a land use compared to agriculture; relatively good productivity can be achieved on poorer quality sites (Farrelly et al. 2011). The positive trend in NPVs over time is particularly interesting, especially in light of the fact that planting rates have generally declined since 2002. The forest premium was increased a number of times over this period, which offers some explanation of the rise in NPVs. However, there was a decline in agricultural profitability during this period as input prices rose while output prices

Table 5: *Soil category (SC) and yield class (YC) specific NPVs (€ ha^{-1}) for forestry replacing a cattle system with positive values in bold. Sample sizes are included in brackets. The soil categories are defined in Table 2.*

Year	SC1 / YC24	SC2 / YC24	SC3 / YC20	SC4 / YC20	SC5 / YC18	SC6 / YC14
1995	−5,952	**8,234**	**1,747**	−1,914	**1,583**	**2,428***
	(9)	**(5)**	**(30)**	(57)	**(42)**	**(2)**
1996	**224**	**2152**	**435**	**1,190**	**1,544**	**1,696***
	(7)	**(2)**	**(24)**	**(41)**	**(23)**	**(2)**
1997	−825	**905**	−167	**1,036**	**636**	**1,021***
	(22)	**(15)**	(49)	**(87)**	**(29)**	**(3)**
1998	**688**	**2,009**	**1,748**	**2,690**	**2,396**	**1,881***
	(20)	**(15)**	**(43)**	**(79)**	**(25)**	**(3)**
1999	**2,506**	**2,732**	**1,878**	**3,635**	**3,382**	**1,775**
	(20)	**(17)**	**(54)**	**(88)**	**(27)**	**(4)**
2000	**2,668**	**1,596**	**3,079**	**4,386**	**3,628**	**2,707**
	(24)	**(20)**	**(54)**	**(87)**	**(21)**	**(4)**
2001	**3,645**	**2,690**	**1,985**	**3,820**	**4,789**	**4,059***
	(27)	**(25)**	**(61)**	**(88)**	**(19)**	**(3)**
2002	**2,494**	**4,379**	**3,476**	**4,524**	**4,217**	**4,366***
	(31)	**(27)**	**(73)**	**(108)**	**(27)**	**(3)**
2003	**4,165**	**3,829**	**3,200**	**4,701**	**4,102**	**4,145***
	(26)	**(30)**	**(52)**	**(102)**	**(29)**	**(3)**
2004	**3,111**	**2,263**	**2,646**	**4,465**	**4,106**	**4,287***
	(25)	**(35)**	**(68)**	**(101)**	**(39)**	**(3)**
2005	**2,807**	**2,824**	**3,150**	**4,398**	**5,253**	**4,456***
	(36)	**(38)**	**(55)**	**(95)**	**(32)**	**(1)**
2006	**5,119**	**3,060**	**2,586**	**5,383**	**5,520**	**4,027***
	(37)	**(30)**	**(50)**	**(87)**	**(27)**	**(2)**
2007	**3,227**	**1,679**	**4,389**	**6,145**	**6,062**	–
	(37)	**(32)**	**(51)**	**(89)**	**(28)**	
2008	**4,205**	**4,966**	**5,730**	**5,595**	**4,984**	**4,764***
	(41)	**(29)**	**(51)**	**(81)**	**(32)**	**(2)**
2009	**4,224**	**4,942**	**5,860**	**6,290**	**5,869**	**2,564***
	(39)	**(36)**	**(52)**	**(74)**	**(31)**	**(1)**

*Very small sample size ($n \leq 3$)

remained relatively stable (Hynes and Hennessy 2012). The results of this study suggest that the financial reward for converting agricultural land to forestry is unlikely to be a driver of the decline in planting rates. Forest-related land-use decisions are driven by a combination of market drivers, policy variables, owner characteristics and land conditions (Beach et al. 2005). Thus future investigations of afforestation patterns may benefit from examining additional factors that may be

Table 6: *Soil category (SC) and yield class (YC) specific NPVs (€ ha⁻¹) for forestry replacing a sheep system with positive values in bold. Sample sizes are included in brackets. The soil categories are defined in Table 2.*

Year	SC1 / YC24	SC2 / YC24	SC3 / YC20	SC4 / YC20	SC5 / YC18	SC6 / YC14
1995	−614	−687	**728**	**1,144**	**3,108**	**2,012**
	(29)	(38)	**(40)**	**(37)**	**(58)**	**(7)**
1996	−1,353	−1,951	−178	**1,193**	**2,913**	**1,675**
	(22)	(30)	(45)	**(28)**	**(58)**	**(5)**
1997	−1,428	−884	−974	−360	**2,565**	−304*
	(19)	(27)	(28)	(27)	**(47)**	(3)
1998	−809	**1,075**	**1927**	**1,377**	**4,344**	**3,783***
	(19)	**(23)**	**(24)**	**(28)**	**(42)**	**(3)**
1999	**709**	**2,149**	**2,950**	**2,623**	**4,613**	**4,027***
	(14)	**(30)**	**(25)**	**(22)**	**(38)**	**(3)**
2000	**1,059**	**2,902**	**2,793**	**3,722**	**5,867**	**3,518***
	(16)	**(29)**	**(24)**	**(21)**	**(37)**	**(2)**
2001	**332**	**205**	**2,069**	**2,667**	**4,515**	**3,038***
	(17)	**(34)**	**(25)**	**(20)**	**(36)**	**(2)**
2002	**546**	**1,302**	**2,883**	**3,323**	**4,558**	**3,693***
	(15)	**(34)**	**(24)**	**(19)**	**(35)**	**(2)**
2003	**26**	**3,874**	**2,213**	**3,084**	**3,490**	**2,673***
	(14)	**(34)**	**(27)**	**(22)**	**(37)**	**(3)**
2004	**887**	**3,120**	**3,409**	**3,924**	**5,836**	**4,175***
	(16)	**(32)**	**(29)**	**(20)**	**(34)**	**(3)**
2005	−645	**2,056**	**3,624**	**3,399**	**4,864**	**4,189***
	(17)	**(28)**	**(30)**	**(16)**	**(35)**	**(3)**
2006	**274**	**2,677**	**3,157**	**4,411**	**4,576**	**3,243***
	(17)	**(29)**	**(31)**	**(18)**	**(36)**	**(3)**
2007	**6,797**	**4,860**	**4,027**	**4,385**	**5,764**	**4,796**
	(11)	**(30)**	**(27)**	**(19)**	**(38)**	**(4)**
2008	**5,184**	**5,567**	**4,780**	**5,196**	**6,933**	**4,648**
	(12)	**(26)**	**(31)**	**(15)**	**(40)**	**(4)**
2009	**6,092**	**5,770**	**5,503**	**5,320**	**5,493**	**3,477***
	(15)	**(26)**	**(30)**	**(14)**	**(35)**	**(3)**

*Very small sample size ($n \leq 3$)

discouraging farmers to convert to forestry. Land prices can have a significant effect on farmer's decision to enter forestry (Kula and McKillop 1998), which may offer some explanation of reductions in planting during years of high economic growth. A negative attitude amongst farmers towards forestry has been identified as a barrier to planting in previous surveys, although regional variances may exist (Ní Dhubháin and Gardiner 1994, O'Leary et al. 2000). Similarly, farmer motivations may play an important part in their land-use decisions with the perceived lifestyle benefits of farming and the productivist mentality of some farmers limiting their interest in

Table 7: *Average soil category specific NPVs (2009 € ha^{-1}) for forestry replacing the agricultural systems, adjusted using the consumer price index and expressed in 2009 values.*

System	SC1 / YC24	SC2 / YC24	SC3 / YC20	SC4 / YC20	SC5 / YC18	SC6 / YC14
Dairy	−19,603.05	−27,229.61	−18,380.64	−14,572.27	−9,189.15	−9,167.08
Tillage	−1,951.58	−5,392.43	−5,211.61	**554.49**	**2,322.32**	–
Cattle	**2,244.23**	**3,134.88**	**3,117.51**	**4,206.74**	**4,410.44**	**3,688.20**
Sheep	**1,052.99**	**2,244.17**	**2,880.49**	**3,405.87**	**5,426.76**	**3,765.59**

adopting what amounts to a major change in enterprise away from traditional farming (McDonagh et al. 2010). Farming and the production of food may thus provide a satisfaction that forestry and the production of timber lacks even where the latter is the financially optimum land use. Given the requirement to replant after clearfelling, the decision to plant trees is essentially a permanent one, which may act as a further disincentive. Restrictions on afforestation in environmentally sensitive areas may have a negative impact on afforestation rates locally (Collier et al. 2002). In addition, thresholds of forest cover may be reached in some parts of the country where land availability is restricting expansion (Upton et al. 2012). Uncertainty surrounding the outcome of renegotiations of the EU Common Agricultural Policy may also be influencing a farmer’s decision on a long-term and permanent land-use change, such as forestry, although this issue has not been examined in detail.

Although an exact breakdown of the area of land under different agricultural systems is not available, approximately 80% (3.4 million ha) of all agricultural land in Ireland is used for grass, including pasture, silage and hay, 11% (0.5 million ha) for rough grazing and only 9% (0.4 million ha) for crop production (Hynes and Hennessy 2012). As the sampling for the NFS is based on system and farm size rather than soil quality it is not possible to identify the proportion of Irish farms or agricultural area would benefit from conversion from the results of this study. However, the results suggest that land that was previously used as rough grazing or grass production on lower quality soils might produce a greater financial return if used for forestry. Ireland may adopt a significant expansionary agricultural policy in the future with the Food Harvest 2020 strategy laying out targets for agricultural production, including a 50% increase in milk output (Department of Agriculture, Fisheries and Food 2010). It is difficult to identify how such targets will impact on land use, but if increased output leads to an increase in the profitability of competing agricultural systems, the relative profitability of afforestation may suffer in the absence of a comparable increase in revenue from increased timber prices or supports. Alternatively, if increases in agricultural production are focused only on the best quality land, this could result in the availability of marginal land for alternative uses (Feehan and O’Connor 2009).

A number of potential shortcomings of the study should be noted. The data employed in this analysis are based on actual farm data derived from the NFS, whereas income from timber production is derived from theoretically optimal management. It is recognised that farms in Ireland may not be managed in a financially optimal way and that decoupled payments may be partly subsidising unprofitable farm production (Howley et al. 2012). Thus, a comparison between optimal forest management and real agricultural enterprises may be somewhat biased. In a survey of farmers who had planted forests, Ní Dhubháin et al. (2010) found that although the majority had employed professional foresters to establish their forest, most planned to manage it themselves but lacked knowledge of management practices. As the private estate matures, the potential will arise to examine the management efficiency of private owners over a full rotation and produce a more accurate financial examination of land conversion. It is also important to note that the analysis was based on an average hectare, but farmers may possess a number of parcels of different levels of quality, which may or may not produce a financial benefit if converted to forestry. In addition, this study focuses on a single rotation of between 38 and 46 years and it is important to note that subsequent rotations would not benefit from premium payments, which could have a significant impact on farm income. Although reforestation costs are accounted for in the calculation which reflects future costs, the approach does not examine the longer time horizon, which may be of particular concern to some farmers, such as those with successors.

The agricultural gross margins included in the study are net of subsidies and it is thus assumed that farmers who planted would not lose out on agricultural subsidies. With the introduction of the single farm payment in 2005, farmers had the option of consolidating their entitlements on unplanted land and thus retain their payment. In this study, it was assumed that before this period farmers could increase stocking levels on unplanted land and thus not lose out on subsidies after afforestation. An examination of the effect of entering forestry on agricultural subsidies would require a detailed breakdown of enterprise, stocking rates, and land ownership and subsidy schemes at the individual farm level; this was deemed to be beyond the scope of the study. Future research in this area may attempt to examine this issue in more detail but is unlikely to substantially change the overall findings of the study. In addition, it was assumed that timber prices did not change in real terms over the period. This approach follows the assumptions of previous authors (e.g. Clinch 1999, McCarthy et al. 2003) and was considered reasonable given the limited availability of timber price data and the long-term nature of the investment. Finally, economic examinations of land conversion are increasingly accounting for environmental and social outcomes (e.g. Clinch 1999). This study focused solely on the financial outcome of land conversion for the landowner. Future examinations of the issue might benefit from accounting for the more general economic outcomes of such a conversion, including effects on employment and local economic activity and net carbon sequestration.

Conclusion

The financial consequences of converting agricultural land to forestry is of primary concern to forest policy in Ireland and to the achievement of afforestation goals in particular. Historically, forestry has always been associated with lower quality soils in Ireland. This study highlights the competitiveness of forestry with other land uses and the importance of soil quality in understanding the potential financial impacts of land conversion. Forestry is a good financial option on land used for cattle and sheep farming, with the potential for lower quality soils to deliver significantly higher NPVs from forestry than agriculture. In addition, forestry has become more competitive over the time period 1995 to 2009, which is in contrast to patterns in afforestation rates.

Practical Implications

- Forestry can be a good financial option for cattle and sheep farms in Ireland over a single rotation but is unlikely to compete financially with dairy systems.
- Soil quality plays an important role in understanding the financial outcome of converting land to forestry. The results suggest that forestry has a greater competitive advantage on poorer quality soils.
- Forestry has become more competitive over time in comparison to agriculture, which suggests that decreases in afforestation rates in recent years have not been driven solely by the financial outcome of land conversion.

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The use of wood as a renewable source of energy in Ireland – developments and knowledge gaps in the control of wood fuel quality

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Abstract

In Ireland, on the basis of recent consumption and a favourable policy environment, the use of wood for energy is increasing. However, there are issues to address in order to realise policy targets for increasing wood energy consumption. Among these issues is a need for information on the impact of wood properties on the fuel quality of wood. Comprehensive knowledge of wood fuel properties assists in the optimisation of operations concerned with the harvesting, seasoning, processing and conversion of wood into energy. In Ireland, wood fuel property databases of forest biomass fuel sources are absent. This paper documents an overview to the developments that have necessitated a need for such databases, and current research that is being conducted to address knowledge gaps on the wood properties that have an impact on fuel quality.

Keywords: *Wood, energy, research, quality, trade.*

Introduction

In Ireland, consumption of wood for energy has increased in recent years for a number of concerns. The heavy dependence on finite resources of imported fossil fuels, declining indigenous energy production, and the adverse effects of climate change have been the key factors driving this increase. In response to these issues, a series of policies have been ratified, initially out of concerns for global climate change. The Kyoto Protocol set out aims to reduce greenhouse gas emissions (GHG) by 5.2% globally. Ireland, as a signatory of the Kyoto Protocol, has agreed to limit the growth in GHGs to 13% above 1990 levels by a target period of 2008–2012 (North and Healion 2003, Government of Ireland 2007). The Kyoto protocol commitments thus instigated a number of initiatives by the Irish Government to formally develop strategies in the effort to mitigate climate change. Among these strategies included increasing the use of renewable energy resources. The Energy Policy White Paper, in particular the Sustainable Energy Sub Programme, committed to an investment of €276 million for the development of a renewable energy sector in Ireland over the course of the National Development Plan (NDP) 2007–2013 (Department of Communications, Marine and Natural Resources 2007a). The Irish Bioenergy Action Plan outlined where this Government

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investment should be implemented for the development of a renewable energy sector in Ireland, including recommendations for increasing wood energy consumption (Department of Communications, Marine and Natural Resources 2007b). The EU Renewable Energy Directive (RED, 2009/28/EC) set out a commitment that 20% of total energy use is to be derived from renewable energy resources by 2020. In accordance with this directive, Ireland has committed to a 16% target for renewable energy resources by 2020 under the National Renewable Energy Action Plan (NREAP 2010). Targets under this plan relevant to wood consisted of the following (NREAP 2010).

- 12% renewable heat energy generation by 2020;
- 30% co-firing with biomass at the 3 peat-fuelled power plants by 2015;
- 800 MW of Combined Heat and Power by 2020.

The realisation of these targets poses significant challenges. Despite a favourable policy environment, the consumption of wood for energy in Ireland is underdeveloped. This paper documents the incentives in place to assist in the development of a wood energy sector in Ireland, and the challenges in maintaining and increasing consumption to fulfil policy targets. Research to support the development of a wood energy sector will also be documented. In particular, this paper will focus on research into wood fuel trade standardisation and quality control, as these have an influence on instilling consumer confidence into using wood for energy.

Emergence of wood energy consumption

In Ireland, there is an unsustainable reliance upon imported fossil fuels, as 95% of total primary energy requirement (TPER) is derived from fossil fuels and 88% of TPER is imported (Dennehy et al. 2012). This leaves Ireland in a precarious position in attempting to maintain security of fuel supplies. As a result the consumption of renewable energy resources should be increased (wind, solar, geothermal, biomass, tidal, wave and hydro), because they are underutilised, indigenous and do not pollute the atmosphere (O'Rourke et al. 2009). In 2011, the contribution of renewable energy to TPER was 6.5% and fell under three sub-categories; electricity (RES-E), heat (RES-H) and transport (RES-T) (Dennehy et al. 2011). Wood contributes mostly to RES-H consumption. Moreover, wood can also contribute to RES-E generation by means of co-firing and combined heat and power (CHP). Co-firing refers to electrical energy generation through the mixture of biomass and non-biomass sources, whereas CHP is a single process where thermal and electrical energy is generated together (REFIT III 2012). RES-H accounted for 5% of all thermal energy produced in Ireland during 2011, with 77.5% derived from biomass fuels in general (Dennehy et al. 2011). Since 2008 to the present, a series of documents have provided specific year-by-year estimates of wood energy consumption in addition to those incentives already in place to increase its use (Knaggs and O'Driscoll 2008, Knaggs and O'Driscoll 2012b). In 2011, 33% of the total round-wood harvest in Ireland was used for energy purposes and has made an overall contribution of 0.81% to TPER (Knaggs and O'Driscoll 2010, Knaggs and

Table 1: *Consumption of domestic, commercial and industrial wood fuel products (per 000m³) during the period of 2008-10 (O'Driscoll 2011).*

Product	End user	2008	2009	2010
Firewood	Domestic heating	171	184	199
Roundwood chipped in forest	Commercial heating	63	53	39
Short rotation coppice	Commercial heating	1	4	1
Wood pellets & briquettes	Domestic heating/commercial heating	82	110	121
Charcoal	Domestic use	2	2	2
Energy and forest products industry consumption	Process drying/heating/combined heat and power	384	418	554
	Total	**703**	**791**	**916**

O'Driscoll 2012b). Table 1 provides a breakdown of the consumption of wood for energy in Ireland.

Table 1 indicates that the forest products industry is the largest consumer of wood energy at 55–60% of the total. Markets for densified fuels such as wood briquettes and pellets have also been increasing in recent years in Ireland, as they are a cost competitive heating alternative to oil and gas for domestic and commercial heating (Knaggs and O'Driscoll 2008). Firewood for domestic use has also increased in recent years, particularly due to the increased availability of wood from private sector first thinnings (Knaggs and O'Driscoll 2012b).

The emergence of this increased use of wood for energy also coincides with the development of incentives and other policy mechanisms to promote an increase in its use. A carbon tax on fossil fuel sources was introduced by the Irish Government through the Budget and Finances Act 2010, with exemptions made for renewable energy resources and participants in Emission Trading Schemes (ETS) (Department of Finance 2010). This tax included a charge of €15 tonne^{-1} of CO_2 emitted, since increased to €20 tonne^{-1} (Department of Finance 2010, Department of Finance 2012). Coinciding with the introduction of this tax, fossil fuel consumption has reduced, but this is mainly due to the economic downturn Ireland has experienced (Gargan 2012). These carbon tax regimes initially covered fossil fuels such as mineral oil and gas, whereas solid fuels such as coal were not included. This was due to a need for the development of trade specifications for the sulphur content levels allowable for residential consumption of coal in Ireland (Department of Finance 2010, Gargan 2012). However, solid fossil fuels such as coal and peat have now been ratified for inclusion under carbon tax regimes as of the 1st May 2013 (Revenue Commissioners 2013).

Contractually binding fixed price tariff mechanisms for renewable energy producers over the course of fifteen years under the Renewable Energy Feed-In-Tariff scheme is another example of an incentive to stimulate wood energy consumption (REFIT III 2012). A variety of grant schemes with funds totalling €89 million have been made available under the direction of the Sustainable Energy

Authority of Ireland (SEAI) (Knaggs and O'Driscoll 2010). Domestically and commercially, the Greener Home and ReHeat schemes provided grants for the installation of renewable energy technologies. Among the technologies approved for grant aid are wood chip and wood pellet stoves and boilers (Knaggs and O'Driscoll 2010). Other grants available include the CHP scheme, which provides grants for the installation of biomass powered CHP facilities (Knaggs and O'Driscoll 2010).

According to Phillips (2011) there are three wood pellet manufacturing facilities and three CHP plants operating in Ireland using wood fuel. As of 2009, products such as wood chip, sawdust and pellets contributed to 66,000 tonnes to co-firing of peat with biomass at Edenderry Power (Reilly 2010). This biomass consumption for co-firing has since increased to 156,000 tonnes as of March 2012, with the majority of this biomass sourced from the sawmilling and forestry sectors (Bord na Móna 2012). An increase in 500,000 tonnes of biomass fuel is anticipated to be required for co-firing by the year 2020 in accordance with NREAP (2010) co-firing targets of biomass with peat. However, in order to meet such demand, not all fuels will be derived from wood biomass (Reilly 2010, Knaggs and O'Driscoll 2012a). The availability of incentives, demands for co-firing and the installation of wood pellet manufacturing and co-generation plants has created a supply and demand situation for wood fuel products. Ultimately, an appraisal of the different policies in place to incentivise wood energy consumption can only be measured over time in terms of their effectiveness, as most of this increase in wood biomass consumption in Ireland has occurred over course of five-six years. In addition to the incentives, there are issues to address if further growth in the use of wood for energy in Ireland is to be encouraged. Forecasting the supply and demand of raw material harvested from forest resources is essential to facilitate further developments and investment to increase the use of wood for energy.

Forecasting round wood supply and demand

Phillips (2011) compiled an all-Ireland round wood supply forecast for the 2011–2028 period. In conjunction, the COFORD Round Wood Demand Group (CRDG 2011) compiled demand scenarios for round-wood over the 2011–2020 period. Both reports concerned the wood processing and energy sectors. A key output from Phillip's (2011) forecast was that a large contribution of round-wood will be available from private sector thinnings, mostly from forests established in the last 20–30 years. The thinning area in Irish forests has been forecasted to double from 22,800 ha in 2011 to 49,400 ha in 2028 (Phillips 2011). The availability of round-wood volume from private and state forests in Ireland has been forecasted to increase from 3.79 million m^3 in 2011 to 6.95 million m^3 in 2028 (Phillips 2011). The majority of this round-wood contribution will come from coniferous species, that include spruce species (84%), lodgepole pine (*Pinus contorta* Dougl.) (9%) and other conifers (7%).

Phillips (2011) forecast also included information about resource availability for energy production, and estimated an increase from 1.07 million m^3 in 2011 to 1.75 million m^3 in 2028. The CRDG (2011) forecasted round-wood demand for conventional uses and energy generation. Wood energy demand forecasts were based on scenario models formulated by the SEAI for the period 2011–2020. The CRDG estimated that demand for wood energy will nearly double from 1.6 million m^3 to 3.1 million m^3 during the forecast period of 2011–2020. Wood for energy supply in 2020 is estimated at 1.5 million m^3 by Phillips (2011), indicating a considerable shortfall compared to the 3.1 million m^3 2020 demand scenario. In addition to this shortfall there are other issues regarding the mobilisation of material from thinnings to meet such supply and demand.

Issues with the mobilisation of wood for energy supply and demand

In the private forest sector, despite the forecasted increase of round-wood availability from first thinnings, there are constraints to mobilising this resource. Insufficient economies of scale result from small average plantation sizes of 8 ha and individual plantations that can range from 1–2 ha in size (Fennessy 2005, Byrne and Legge 2008). Moreover, there are a number of factors that will further affect the mobilisation of thinnings from the private forest sector. These factors include a landowner's management objectives, site access difficulties, poor ground conditions, the risk of windthrow, excessive infrastructure requirements, lack of knowledge on how to conduct thinning operations, marketing issues, perceived unfavourable prices for round-wood, and high harvesting costs (Maguire et al. 2010, Casey and Ryan 2012). Another facet to the mobilisation problem is that the competition for round-wood between the sawmilling and wood energy sectors will further affect supply and demand forecast scenarios (Phillips 2011). Nonetheless, a number of initiatives have been developed in recent years that may affect the allocation of first thinnings for energy use.

Initiatives for thinning mobilisation and supply chain development

To resolve mobilisation issues and initiate first thinning in privately owned plantations, farm forest owner groups supported by Teagasc have developed in recent years. The objectives of such groups are to collectively thinn plantations and develop markets for wood processing and/or energy generation in the private forest sector. There are currently 26 farm forest owner groups in total around Ireland (Teagasc 2012). The efficacy of these groups in delivering upon their objectives may possibly be reflected in the record number of felling license applications made to the Forest Service during 2012 from private forest owners (Magner 2012), coupled with favourable round wood prices for first thinnings in recent years (Casey and Ryan 2012). In 2011, 386,000 m^3 of thinnings were harvested from privately owned forests, representing 14% of the total round wood harvest, the remainder attributable to Coillte (84%) and imports (2%) respectively (Knaggs and O'Driscoll 2012b). This emergence of private forest sector first thinning coincides with an increase of domestic firewood consumption. The firewood market has experienced a 35% increase from 2006 to 2011 (O'Driscoll 2011). Total firewood consumption derived from indigenous sources in 2011 was 214,000 m^3, although this may be an underestimate as markets typically operate on a local basis, thus making it difficult to derive accurate estimates (Knaggs and O'Driscoll 2012b, Magner 2012). Despite this increase in thinning and fire wood consumption, the harvesting of thinnings for energy is only one operation contained within a broader supply chain from producer to consumer.

Wood fuel supply chains

Until recent times in Ireland, there was a lack of research into all the aspects of the use of wood for energy. The limited number of articles included guidelines for the construction of portable firewood mills (Donovan 1946), in addition to notes on firewood extraction (Deasy 1947). A considerable body of research into the use of wood for energy was instigated in Ireland as a response to the oil crisis of the 1970s. This research included trials examining forests established at tighter spacings than normal to maximise dry matter production for energy consumption (McCarthy 1979), seasoning trials of small sized round-wood (Savill 1979), biomass sampling from the point of view of nutrient removals as a result of total tree harvesting (Carey and O'Brien 1979, Carey 1980), and an appraisal of wood biomass availability within State-owned forests for energy purposes (McCarthy and Keogh 1983). There has been little research into the use of wood for energy from the 1980s and onward. The only significant bodies of work during this intervening period were an evaluation of the processing of above-ground logging residues from clearfell areas for the production of wood briquettes, an evaluation of above ground logging residue harvesting supply chains, and a feasibility study into the development of a wood energy sector in Ireland (Coggins 1996, Hoyne and Thomas 2001, North and Healion 2003). More recently, the Forest Energy Programmes of 2006–2008 were the first comprehensive published works concerning the development of cost-competitive wood fuel supply chains appropriate to Irish conditions (Kofman and Kent 2007, Kent et al. 2011). The programmes provided for support measures that stimulated owners to carry out to first thinning operations in private plantations.

The programmes involved an examination of the feasibility of using Scandinavian wood fuel harvesting and processing technologies that had not been previously trialled in Ireland. These included the production of wood chip material for industrial and domestic purposes, in addition to small-scale firewood supply chains from privately-owned forest plantations. Trials were mostly conducted on first thinning sites of both conifer and broadleaf tree species in different locations throughout Ireland. Other trials examined the storage and seasoning of wood fuel assortments in a forest environment and at dedicated terminals. Another feature of the programme was the testing and evaluation of the physical and chemical properties of wood chip and firewood. The physical and chemical properties of wood have an obvious influence on the quality of wood energy products, and therefore affect supply chain optimisation and efficiency.

Quality control for wood fuel products that are emerging and already established

In Ireland, the increased use of wood for energy generation in recent year's means, there is a compelling need to analyse wood properties that influence energy conversion and ensure transparency in the indigenous and international trade of wood fuel. The reasons for this are twofold. First, to ensure that wood enters the energy market on a cost-competitive basis with well-established fossil fuels. Due to comparatively higher oxygen content, wood is of a lower fuel density in comparison to fossil fuels such as coal, gas and oil (Dembris 2004, Swithenbank et al. 2011). Second, international trade of wood fuel products will be a likely scenario for countries that lack the indigenous resources to fulfil policy predictions for increasing wood fuel consumption (Hillring 2006). This is especially the case in Ireland, given the constraints in the supply of thinnings from the private forest sector, competition with the sawmilling sector and overall predicted shortage of raw material to meet demands for wood energy into the future. There is also a need to establish wood quality parameters for the testing of emerging and established wood fuel products. A key highlight of previous trials on the Forest Energy Programme was the benefits of utilising all the partitions of a tree, rather than the production of wood fuel products derived from round-wood only.

Irish studies into Sitka spruce (*Picea sitchensis* (Bong.) Carr.) have found that the majority of the total biomass accumulated in trees is in stem wood sections (Carey and O'Brien 1979, Carey 1980, Green et al. 2007). The remaining biomass, known as logging residues, is material left behind on site after the harvesting of round-wood from stem wood sections. This material includes branches, foliage, unmerchantable stem sections and stumps that could be harvested for energy from clearfell areas (Hakkila 2004, Alakangas, 2005). The quantification and characterisation of logging residues for conversion into energy in Ireland has been identified as a knowledge gap (Kent et al. 2011). In addition, the harvesting and processing of logging residues has the potential to reduce the predicted shortages in wood fuel supply from now until 2020 (Kent 2012). Although logging residues are typically harvested from clearfell areas, trials in Ireland have found that harvesting whole trees from first thinning sites proved to be a lower cost operation. This is due to a twofold increase in the biomass that can be harvested from whole trees in contrast to standard round-wood harvesting for energy only (Kent et al. 2011). Residue material was partially included in Phillips (2011) energy supply forecast in the form of unmerchantable <7 cm diameter stem sections, but neither the potential contribution of harvesting whole trees from first thinnings, nor logging residues from clearfell areas was estimated. Against the background of potential wood fuel products derived from logging residues, in tandem with wood fuel products that are already established, a number of initiatives concerning quality control in the regulation of trade between wood fuel producers and consumers have developed in recent years in Ireland.

Standardisation and initiatives to regulate wood fuel trade

In wood energy terms, quality is defined by the influence of fuel properties on optimal energy output (expressed as megajoules) or kilowatt hours, expressed as megajoules (MJ kg^{-1}) or kilowatt hours (kWh m^{-3}) (Alakangas et al. 2006, Kofman and Kent 2007). Over the last decade the European Commission (EC) mandated the development of standards for the harmonisation of wood fuel trade within and outside the EU (Alakangas et al. 2006). Standards are a set of rules to ensure quality which are described in unambiguous documents designed for repeatable and reproducible use (Loibneggar 2011, Solid Standards 2011). With this mandate for trade standardisation, the solid biofuels Technical Committee (TC) 335 was formed to develop standards in biomass trade (Kofman 2010). Ireland is represented on TC 335 through the National Standards Authority of Ireland (NSAI) (Kofman 2012). Other developments included the BioNorm project which evaluated the standardised testing procedures for both physical and chemical properties of wood, its suitability for energy conversion technologies, and the optimum utilisation of machinery operating in the field for the production of wood fuel (Alakangas et al. 2006, Obernberger et al. 2006).

Standards typically begin as Technical Specification (TS) drafts. After a period of use for five years, TS drafts are evaluated as to whether or not they should be upgraded to a European Standard (EN) (Kofman 2010, Solid Standards 2011). After 10 years of development, 28 EN standards have been adopted by participants and are now serving a role in the preliminary development of international trade standards for solid biofuels (Kofman 2012). Standards specify suitable terminology common to participants (e.g. EN: 14588: 2010), specify quality parameters for wood fuel products EN: 14961-1 2010 and to define quality assurance specifications for use between wood fuel producers and consumers EN: 15234-1 2011. The latter quality assurance standard is based upon an internal agreement of fuel specifications between producers and consumers (Loibneggar 2011). In Ireland, independent audits of internal trade agreements between wood fuel producers and consumers has been initiated in recent years through the wood fuel quality assurance scheme (WFQA), instigated by preliminary testing of European Standards on the Forest Energy Programme (Kent 2009). The WFQA is an industry-led initiative to certify wood fuels produced in Ireland in accordance with the National Working Agreement 4: 2009: Woodfuel Quality Assurance-Requirements (NSAI 2009). The resulting WFQA label is a quality mark awarded to wood fuel producers who meet the standards of external audits (Kofman 2010). Standards also exist for the scientific lab testing of the physical and chemical properties of wood fuels. For practical purposes, the implementation of such standards are required for quality assurance audits of wood fuel producers, and in the settlement of product quality disputes between producers and consumers (Kofman, 2010).

In relation to trading wood fuel there are a number of normative parameters that have to be specified under standardised trade procedures. The origin of the wood fuel product, moisture and ash content are among the most important parameters to specify when trading wood fuel EN: 14961-1 2010. Other parameters that are necessary to specify depend upon the type of wood fuel being traded, for example the particle size of wood chip EN: 14961-1 2010. Other properties are typically informative (voluntarily specified) when trading wood fuel such as heating values, presence of volatile matter and chemical properties as some examples. However all wood fuel properties have a role to play in the optimisation of energy conversion processes.

Physical and chemical properties of wood

The primary energy conversion process of wood is by means of combustion

(Obernberger et al. 2006). A thermochemical process, combustion essentially converts the solid organic components of wood into water (H_2O) and carbon dioxide (CO_2), releasing heat energy (Obernberger et al. 2006). Optimum combustion ensures that maximum energy output has been achieved; wood has fully volatilised, minimal emissions of GHGs and low amounts of wood ash have been produced, all depending upon the boiler capacity and fuel type (Savoleinen and Berggren 2000, Obernberger et al. 2006). To ensure optimum combustion, detailed analysis of physical and chemical wood properties are a necessary prerequisite (Ragland et al. 1990). There are a variety of properties that affect combustion efficiency. These properties include the calorific value of wood, moisture content, basic density, bulk density, particle size, the proportion of volatiles, chemical composition, ash forming elements and the quantity of impurities such as fungi, soil and stones (Savoleinen and Berggren 2000, Loibneggar 2011).

In its freshly felled state, wood typically contains 40–60% water and the remainder is dry matter biomass. The organic constituents of wood biomass consist of the long chain polymers cellulose (40–45% of total weight), hemicellulose (25–40%) and lignin (24–33% for conifers and 16–25% for broadleaves) (Alakangas 2005, Bowyer et al. 2007). The elemental composition of these organic constituents directly relates to the quantity of volatile chemicals released during combustion. Analysis of volatiles in wood is termed either as ultimate or proximate analysis. Proximate analysis of wood biomass consists of 80–90% volatiles, meaning it will give up this proportion of its weight to forming gases in the pyrolysis phase of combustion, the remainder being solid carbon (Savoleinen and Berggren 2000, Alakangas 2005). Ultimate analysis refers to the elemental composition of wood. The elemental composition of wood consists of 45–55% carbon (C), 4.5–6% hydrogen (H), 40–45% oxygen (O), 0.1% nitrogen (N), 0.1% sulphur (S) and 0.3–0.5% ash (Baker 1983). This composition is relatively uniform between different tree species (Bowyer et al. 2007). Wood also contains solid incombustible major and minor mineral trace elements that constitute wood ash (EN: 14588: 2010, Obernberger et al. 2006). Ash has a large diversity of major and minor constituent elements including aluminium (Al), antimony (Sb), arsenic (As), barium (Ba), cadmium (Cd), calcium (Ca), chlorine (Cl), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), silicon (Si), sodium (Na), sulphur (S), thallium (Tl), titanium (Ti), vanadium (V) and zinc (Z) (Obernberger et al. 2006). The concentration of these major and minor elements are relevant to and can affect the optimisation of energy conversion processes, including ash melting behaviour, fly-ash formation in chimney flues, aerosol emissions, particulate emissions, air purity and toxic elements. The elements specifically involved in the latter issues and the level of concentrations in different solid biofuels, including wood biomass, are reviewed extensively by Obernberger et al. (2006). The mineral elements of primary concern from a negative viewpoint are the quantities of Cl, N and S. Cl has the capability to react with K and Na to cause corrosion on heat transfer surfaces and chimney flues in boilers, whilst N and S possess the capability to convert into GHGs such as nitrous oxide (NO_X) and sulphur oxide (SO_X) (Hakkila 2004, Alakangas 2005, Obernberger et al. 2006). However wood generally has low levels of Cl, N and S. Cl is an issue with wood fuels that contain a high proportion of foliage (Alakangas, 2005). In addition wood emits low levels of NO_X and SO_X provided combustion is optimised (Obernberger et al. 2006).

The physical and chemical properties of wood may vary for a variety of reasons. Physical properties such as moisture content can vary according to species, tree partitions, age, seasons, location, proportions of sapwood to heartwood and the time of year wood fuel products are in storage (Savoleinen and Beggren 2000, Bowyer et al. 2007). Basic density is another source of physical variation in wood fuel and can vary according to species, climatic effects on radial growth, presence of reaction wood, proportions of juvenile and adult wood, between tree partitions, within stems, silvicultural practices and genetic sources (Repola 2006, Bowyer et al. 2007, Jyske et al. 2008).

Calorific values and ash-forming elements are typically classified by the inherent differences between tree parts such as stems, branches and foliage (Nurmi 1993, Werkelin et al. 2005). Investigations have shown that calorific values and chemical element concentrations are greater in the more biologically active parts of trees such as foliage, secondly in branch wood due to greater proportions of bark, descending in order to stem bark and concentrations being lowest in stem wood (Nurmi 1993, Alakangas 2005, Werkelin et al. 2005). As branches and foliage are constituents of logging residue material that can be harvested for wood fuel products, the implications of its harvesting would consequently have an effect on forest ecosystem nutrition dynamics. This is due to the exportation of essential nutrients for tree growth coinciding with intensified harvesting of wood for energy (Karltun et al. 2008). To rectify excessive nutrient exportation, one possible action that can be undertaken is the recycling of nutrients by means of fertilising forests with wood ash (Stupak et al. 2008). Wood ash fertilisation has a twofold benefit. These benefits include the capability of wood ash to neutralise soil pH on soils that tend to be acidic in nature and also reduce the costs of wood ash disposal in landfills resulting from increasing wood fuel consumption (Pitman 2006, Stupak et al. 2008). A synthesis of research into the utilisation of wood ash as a fertiliser in Nordic countries was reviewed by Rauland-Rasmussen et al. (2008). Nordic research has found that application of wood ash does not increase forest productivity on mineral soils, but has proven to be beneficial on less fertile peat type soils. Despite this observation, Rauland-Rasmussen et al. (2008) commented that there was a lack of research into the long term effects (>10 years) of nutrient removals and wood ash application. However this has been since remedied due to recent results accumulated from a 30 year old wood ash fertilisation trial in Finland. Saarsalmi et al. 2012 found that tree productivity was greater in plots where wood ash supplemented with artificial N was applied in comparison to control plots where no fertiliser was applied. N, a key nutrient for healthy tree growth, must be supplemented into wood ash fertilisers, as the naturally occurring N in wood is converted to NO_X during combustion (Obernberger et al. 2006, Saarsalmi et al. 2012). The higher productivity in the fertilised plots was observed by Saarsalmi et al. (2012) to be due to greater soil microbial processes in the circulation of N and C, in addition to higher concentrations of exchangeable Ca, K, Mg and extractable P found within the chemical composition of the soil organic layers. Despite the apparent benefits of utilising wood ash as a fertiliser, there is a complexity of factors to consider. The point at which wood ash is collected during the combustion process, the wood burning temperature, the type of wood fuel product combusted, presence of contaminants, the application method with regard to solubility, the amount applied in the field/ha^{-1}, the timing of application in a forest rotation, soil types, the types of soil organic layers, soil microbial sensitivities and soil water status all influence the suitability of ash as a fertiliser. (Pitman 2006, Karltun et al. 2008, Rauland-Rasmussen et al. 2008, Stupak et al. 2008). In Ireland, research into all the different aspects of wood ash recycling is currently underway (O'Halloran 2010).

Research efforts to address knowledge gaps on wood fuel properties in Ireland
In Ireland, wood fuel property databases of forest biomass fuel sources that have an impact upon fuel quality are absent. One aim of the research being carried out currently as part of the Forest Energy Programme in Waterford Institute of Technology is the development of a wood fuel property database covering the main commercial forest tree species in Ireland. The age-class for the characterisation of wood fuel properties is focussed upon stands ready for first thinning. The six species being investigated include alder (*Alnus glutinosa*), ash (*Fraxinus excelsior* L.), birch (*Betula* spp.), lodgepole pine, Norway spruce (*Picea abies* (L.) Karst) and Sitka spruce. The main fuel properties to be investigated are moisture content and basic density. These are physical properties of wood that have an impact upon energy conversion efficiency. Moisture content is one of the most important wood fuel quality parameters. High moisture content has an adverse effect on the energy generated from wood, can compromise the storage capabilities of wood fuel, and can increase the fuel consumption of trucks transporting wood intended for energy consumption (Hakkila 2004, Serup and Kofman 2005). These factors highlight the importance of developing strategies for harvesting and seasoning wood fuels with a view to reducing moisture content to a point suitable for end-user needs. Current research seeks to investigate the spatiotemporal variation in the moisture content of stem and branch wood partitions. This will aim to identify the most suitable times of year for harvesting and seasoning wood for energy production. The sampling methodology implemented for the measurement of moisture content in stem sections will also allow for an opportunity to investigate the basic density of the same six tree species. Basic density is an important wood fuel quality parameter that describes the potential energy content that may be yielded per unit volume (m^3) from wood fuel products. However, only basic density data for Sitka spruce have been reported for Irish conditions, at least within the public domain (Ward and Gardiner 1976, Gardiner and O'Sullivan 1979, Javadi et al. 1983, Treacy et al. 2000, Ní Dhubháin et al. 2006, Green et al. 2007, Tobin and Nieuwenhuis 2007).

Samples used for the analysis of physical wood fuel properties will be used to create a repository for the analysis of chemical wood fuel properties. This will provide an opportunity to measure calorific values and quantify the major and minor chemical elements associated with wood ash formation. This work will also attempt to collate wood fuel property data generated from the previous Forest Energy Programme, data from private firms, and accredited wood fuel testing centres across Ireland.

Conclusion

In Ireland, on the basis of recent consumption figures and a favourable policy environment, the use of wood for energy is increasing. However, there are issues to address in order to instil confidence into the use of wood for energy. Demands for wood fuel have been predicted to exceed supply in the future, especially if the harvesting and processing of round-wood only for wood fuel is solely relied upon. This in turn will inevitably lead to interest into the harvesting of logging residues that have not been utilised in the past to meet the shortfall in wood fuel supply in Ireland. As a result, research will be required to assess the feasibility of harvesting operations and the characterisation of the physical and chemical fuel properties of whole trees from first thinnings and logging residues from clearfell areas. Furthermore, mobilisation of key forest biomass fuel sources, especially from private forest sector first thinning, is often dictated by individual circumstances. Nonetheless, although private forest sector first thinning is increasing, in addition to firewood consumption, there is a need to address the ramifications of the influence of fuel properties on achieving optimum energy output and the long-term sustainability of ecosystem productivity.

In spite of the policies and incentives in place to promote an increase in the use of wood for energy, without knowledge of the variety of properties that dictate wood fuel quality, consumers will not be able to optimise output from wood fuel. This may affect public and industry confidence into the use of wood fuel products, especially in an energy market where wood fuels have to compete with well-established fossil fuels. Indeed, adoption of European trade standards and initiatives such as the WFQA scheme will help to address the issues associated with wood fuel quality. However, the fuel quality specifications required by individual end users may not necessarily conform to the WFQA requirements and European trade standard specifications. Nevertheless, flexibility is allowed in terms of trade audits between wood fuel producers and consumers EN: 15234-1 2011, and the very purpose of European standards is that they are evaluated every five years by the countries participating in their testing (Alakangas et al. 2006). A good aid in the evaluation of wood fuel product quality and trade standards is a comprehensive knowledge of the fuel properties of forest biomass fuel sources before processing (e.g. round-wood, above and below-ground logging residues).

The development of a database on the fuel properties of wood will serve as a template for the characterisation of wood fuel products derived from different forest biomass fuel sources in Ireland. In addition, this database will also provide a template to evaluate the suitability of European standards for testing different wood fuels under Irish conditions. The resultant data from this project will be made available to wood fuel producers and consumers through dissemination outputs.

These outputs will be in the form of project reports, peer reviewed papers and an online database with a user query interface. Ultimately, it is envisioned that the dissemination of such information will confer an increased degree of confidence to the use of wood for energy in Ireland.

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Deer in Irish commercial forests

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Abstract
The history of deer species, their current distribution and their numbers are summarised, but there is paucity of reliable information about deer populations in Ireland. Aspects of how deer use commercial forests and particular habitat preference are described. The issue of deer in commercial forests in Ireland is discussed in the context of a number of local studies, though there is a lack of knowledge as to the extent of issues discussed. The types of impacts and damage observed in Irish plantation forests, particularly bark stripping and browsing, show the likely effects on the plantation crops. Calculating the potential economic cost of damage is difficult since relatively few studies have been carried out in Ireland, and national baseline quantitative data are lacking. Deer are protected by legislation in the Republic of Ireland and Northern Ireland and there is no formal deer management policy in Ireland.

Keywords: *Red, sika, fallow, Sitka spruce, deer damage.*

Introduction

Three deer species are widespread on the island of Ireland, red deer (*Cervus elaphus*), sika (*Cervus nippon*) and European fallow deer (*Dama dama*) (Figure 1A–C; Carden et al., 2011). Since 2007 there have been numerous reports of the presence of a fourth deer species, Chinese muntjac deer (*Muntiacus reevesi*), at various locations in Ireland (Dick et al. 2009, Carden et al. 2011). The most up-to-date records of this species are from 2013, occurring in 15 different 10 km^2 grid squares in Ireland (National Biodiversity Data Centre 2013) (Figure 1D).

Red deer are not widely distributed in Ireland and occur primarily in the northwest, southwest and east of the country (Carden et al. 2011). Their origins in Ireland have been recently investigated using mitochondrial DNA and the Kerry red deer population are now believed to be direct descendants of an human-mediated introduction from Britain during the Neolithic period approximately 5,000 years ago (Carden et al. 2012). Whilst all other populations of red deer originate from various recent introductions and translocations to Ireland from various British and other populations, in particular during the 19th century (Whitehead 1960, Whitehead 1964, Carden et al. 2012).

Sika were introduced from Japan during the 19th century by Lord Powerscourt to his estate in Enniskerry, Co. Wicklow and distributed to various estates in Ireland including locations in Counties Kerry, Fermanagh and Down (Powerscourt 1884, McDevitt et al. 2009). It is widely recognised that these animals were subsequently

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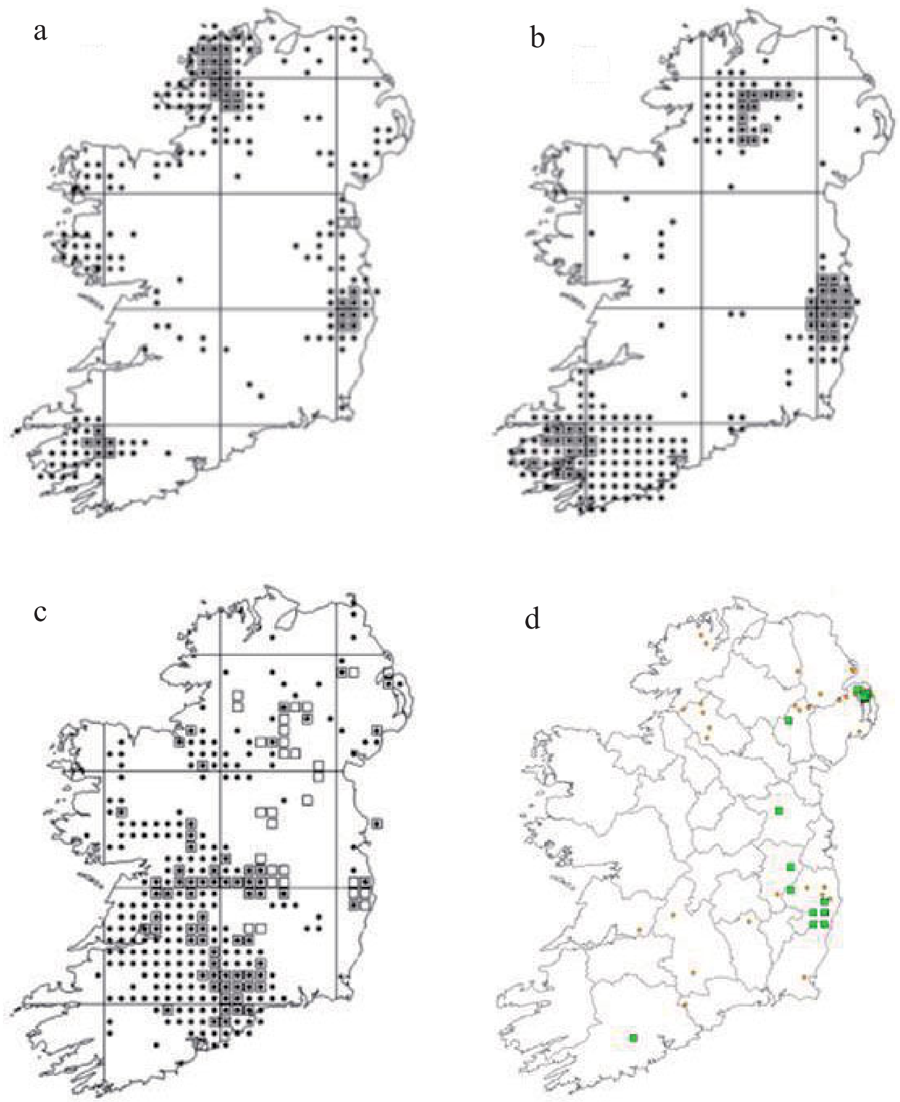

Figure 1: *Taken from Cardin et al. (2011), the distribution of red deer (a), sika deer (b) and European fallow deer (c). Distribution is based on a 10 km square. Each square represents 1,978 records. Dots represent records from 2008. D: Muntjac recordings (d), as of August 2011, were taken from the National Biodiversity Data Centre (2013). Circles represent confirmed sightings and squares represent muntjac deer confirmed as of August 2011.*

released, or escaped, from these estates into the surrounding countryside and became naturalised (Carden et al. 2011). Sika and red deer can interbreed and produce fertile hybrids, and this first occurred on the Powerscourt Estate (Powerscourt 1884) and such hybrids have been detected primarily in the east of Ireland (McDevitt *et al*. 2009).

European fallow deer is the most widely distributed deer species in Ireland (Carden et al., 2011). This species has been in Ireland since its introduction during the 12th century (Sykes 2007) with later translocations in the 18th century (Whitehead 1964). Escapees from enclosed populations through the centuries, particularly in the 20th century, established the species in Ireland (Whitehead 1964).

The overall distribution of the three deer species during a 30-year period (1978 to 2008) show a considerable range expansion: 565% for red deer, 353% for sika and 174% for European fallow deer (Carden et al. 2011). These range expansions relate only to the distribution, but there is less certainty as to the level of increase in the size of the populations (Carden et al. 2011). The method used to survey the distribution recorded only the presence of deer in a 10 km^2 grid square. In general, the distribution of red deer, sika and European fallow deer did not differ from their original reported strongholds originally reported in the 1960s (Whitehead 1960) and the late 1970s (Ní Lamhna 1979). However, red deer are the least widely distributed species in Ireland (Carden et al. 2011). Most of the sika records were found in similar areas of the country, although there were several outlying records which may be a result of illegal translocations (Carden et al. 2011). European fallow deer are the most widely distributed species, although they exhibited the least expansion of all deer ranges during the 30-year period (Carden et al. 2011).

It is difficult to estimate the current population levels of deer in Ireland as national census work has not yet been conducted on Irish deer. Anecdotal reports and media coverage, such as articles in the Irish Examiner by Hickey (2011) and the Irish Independent by Barry (2010), suggest that deer populations are increasing. However, more recently, the Deer Alliance (an assessment committee to oversee the Hunter Competence Assessment Programme (HCAP), a required qualification to shoot deer in Coillte forests in Ireland) reported a significant decline in the deer cull in Ireland for the 2012/2013 season, with approximately 3,000 fewer culled deer compared to the previous season and suggests that there are fewer deer due to excessive poaching (Deer Alliance 2013). However, there are no scientific data available to support this claim. There are few published data regarding deer numbers on the island and recent works noting population trends have not used census data, for example, the population increase noted by Purser et al. (2009) was based partly on numbers of deer shooting licences issued and the annual cull data (deer hunter bag returns based on the deer hunting season) returned by the licenced deer hunters to the National Parks and Wildlife Service (NPWS, within the Department of Environment, Community and Local Government). The numbers of deer hunting licences issued by NPWS have increased every year since 1977, when 231 licences were issued, up to 2012 when 4,501 licences were issued (source: NPWS). According to the annual deer hunter bag returns, for example, from 1997/98 6,173 deer were shot and in 2007/08 24,513 deer were shot according to Carden et al. (2011). There are no data to link the number of deer hunting licences issued to the number of deer present in any given area and therefore, the numbers of deer shot could be a reflection of the number of licences requested rather than a change in deer numbers (Carden et al. 2011). Given these uncertainties, it is important to note that until such time as there are ongoing monitoring programmes of fecundity, birth rates and natural mortality rates of the deer species and a system that monitors culled deer numbers in Ireland (e.g. a tagging system), the annual deer hunter bag return cull figures cannot be validated, verified, or even calibrated.

Several doctoral and M.Sc. theses have been undertaken on various aspects of deer-related ecology in Ireland, although publications from these theses are limited. Some examples include studies based on the comparative ecology and biology of sika and red deer in relation to woodland habitats within Killarney National Park (Raymond 2008, Burkitt 2009), an examination of the sika cull in Co. Wicklow (O'Brien 2000) and browsing impacts on native woodlands of deer in Glenveagh National Park, Co. Donegal (Höna 2009). No post-graduate research could be found on the impacts of deer on commercial forestry in Ireland.

Use of commercial forests by deer

Red deer, sika and European fallow deer are adaptable species that use a variety of habitats, and are primarily ecotone species that are associated with the woodland edge adjacent to grassland type habitats (Harris and Yalden 2008). Red deer generally prefer upland habitats, heaths, native woodland habitats and conifer plantations (Langbein 1997, Staines et al. 2008). In Ireland red deer are noted for inhabiting treeless habitats and colonising plantation forests (Staines et al. 2008). Sika are typically associated with acidic soils and plantation forests, which may be adjacent to heath (Putman 2008). European fallow deer are associated with mature deciduous or mixed deciduous woodland with an established understory, but will also colonise conifer plantations with some open areas (Langbein et al. 2008).

Afforested habitats, including plantations, are used not only for cover but also provide browse for deer species (Moore et al. 1999, Rooney and Hayden 2002, Scott et al. 2009). Pre-thicket forests in particular provide a variety of conditions for many plant species to flourish. Prior to canopy closure, bramble, grasses and other palatable species grow between the developing trees. The young plantation trees also form a proportion of the diet with the tips of lateral and leader shoots, and bark being edible (Putman and Moore 1998, Scott et al. 2009). Once the canopy closes and the understory is reduced due to lack of light, there is less edible plant matter for deer (Catt and Staines 1987, Latham et al. 1996). Nevertheless, closed canopy continues to provide good cover for daytime refuge (Catt and Staines 1987).

Vulnerability of trees may vary with age and type of tree; for example a pre-thicket age broadleaf tree may be more likely to suffer damage, or mortality, than a thicket age or mature conifer. It is accepted that pre-thicket trees are generally more vulnerable to damage than thicket or mature trees. Broadleaf trees are generally more palatable than conifer trees, but the division between age profile and tree type suggests that forest plantations are vulnerable to deer damage (Table 1). In general terms, the 33.6% of the national crop which approximates to pre-thicket may be more vulnerable than the thicket and mature crops which account for 64.6%. The 24.3% of broadleaf cover may be more vulnerable than the 73.9% of conifer cover (derived from Forest Service (2007) data).

The landscape surrounding a plantation has been found to influence how deer utilise a plantation. For example, in the UK broadleaved plantations surrounded by

Table 1: *Age profile and cover of forests within Republic of Ireland, derived from the National Forest Inventory (Forest Service 2007).*

Age profile	Pre-thicket[a] ≤10 yrs	Thicket 11–30 yrs	Mature ≥31 yrs	Temporarily unstocked	Total % area per land-use
% area of conifer	24.9	34.8	14.2	0.0	73.9
% area of broadleaf	8.7	8.2	7.4	0.0	24.3
% area temporarily unstocked	0.0	0.0	0.0	1.8	1.8
Total % age profile	33.6	43.0	21.6	1.8	100.0

[a] Pre-thicket is generally defined as stands <3 m high, and/or where the canopy has not closed, which usually happens before 10 years, depending on species. The minimum age division in the National Forest Inventory 2007 (Forest Service 2007) was 10 years, i.e. 1–10 years, 11–20 years etc.

arable land were found to be less likely to be damaged by fallow deer than those surrounded by other habitat types (Moore et al. 1999). Additionally, the importance of surrounding habitat as significant foraging habitat has been reported in the UK, for example, deer grazing on grasslands, heaths and agricultural lands adjacent to plantation forests (Catt and Staines 1987, Mann and Putman 1989). No such data exist for Ireland.

Are deer a problem in Irish commercial forests?

It has been recognised that deer can have a negative impact on commercial forests in Ireland (Rooney and Hayden 2002), yet there have been few quantitative studies of the interactions between wild deer and commercial forestry in Ireland. Some work has been conducted on closely related topics such as the effects of deer exclusion on natural habitats (Kelly 2002, Perrin et al. 2006, Perrin et al. 2011) and deer grazing in natural and conservation habitats (Mitchell 1990, McEvoy and McAdam 2005, McEvoy et al. 2006) with additional research which examined various aspects of deer ecology/biology and their browsing habits on conservation habitats, including natural woodlands (for example: Larner 1980, Raymond 2008, Höna 2009, Newman et al. (In Press)).

Two comprehensive reports prepared for semi-state agencies (Campbell and Marchbank 2009, Purser et al. 2009) concluded that deer cause economic damage to commercial forests in Ireland primarily through bark stripping and leader browsing (Figure 2). A report that evaluated the potential financial returns from Sitka spruce (*Picea sitchensis* (Bong.) Carr.), concluded that deer can have a negative effect on commercial timber production (Sweeney and Nieunwenhuis 2008). Elsewhere, many studies from other countries, particularly from Britain, have reported deer damage to commercial forest and agricultural crops (Putman and Moore 1998, Moore et al. 1999, Scott and Palmer 2000, Ward et al. 2008, Scott et al. 2009).

It is difficult to determine if deer are a significant problem in Irish commercial forests due to the lack of suitable quantitative data from across the country. As part

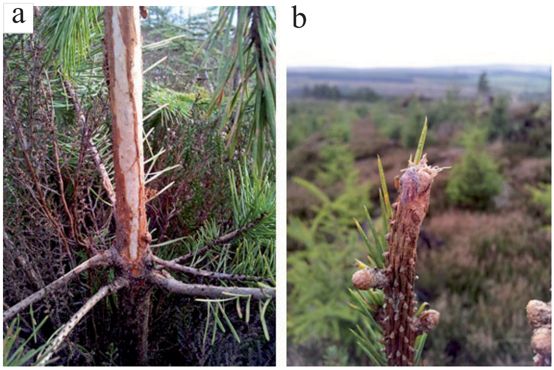

Figure 2: *Example of deer bark stripping to a young lodgepole pine stem (a), and of a Sitka spruce leader shoot browsed by deer (b).*

of an ongoing project on the interaction of deer and commercial forests[1] (Unpublished data; University College Cork 2013) a questionnaire survey of farmers, landowners, hunters, foresters, recreational users of the countryside, and employees of state and semi-state organisations was conducted to judge the public perception of deer. Nearly half (44.5%) of all respondents (1,213 in total) agreed and strongly agreed with the statement that "damage to woodland or forest by deer is a problem" (Figure 3). Clearly the public view is that deer cause damage in forests, but this view cannot yet be substantiated because of the lack of quantitative data.

Damage to trees caused by deer

Bark stripping

Bark stripping by red deer, sika and fallow deer occurs when the bark is stripped

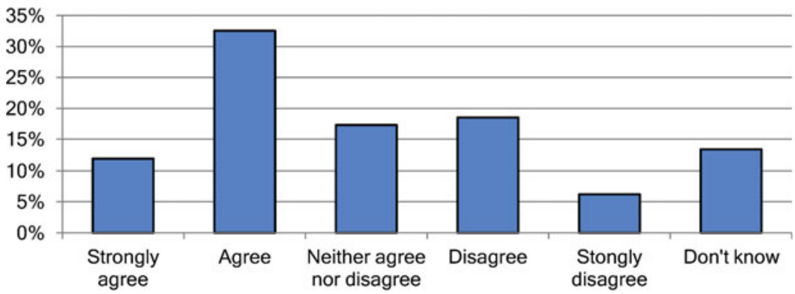

Figure 3: *Results from a stakeholder questionnaire (n = 1,213 respondents) in response to the statement "I think damage to woodland/forests by deer is a problem" University College Cork (2013), unpublished data.*

[1] Unpublished data from a stakeholder consultation survey carried out by the FORDEER research group in 2013, University College Cork.

back to the cambium using the lower incisor teeth to gnaw or strip the bark in an upwards motion (Verheyden et al. 2006) and has been reported to occur when food resources are limited during late winter/early spring (Gill 1992a). Bark stripping may have several negative economic impacts by (i) reducing the value of the timber due to staining of the wood from fungal growth (ii) causing the tree not to grow straight and (iii) excessive bark stripping (ringing of the trunk) and pathogens entering the tree through wounds may lead to the death of the tree (Gill 1992, Gill et al. 2000, Verheyden et al. 2006). An example of bark stripping is shown in Figure 2A.

Sitka spruce is relatively resistant to bark stripping and browsing, while Scots pine (*Pinus sylvestris* L.), oak (*Quercus* spp), larch (*Larix* spp), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and Norway spruce (*Picea abies* (L.) Karst.) are more sensitive to such damage (Gill et al. 2000). A seven-year study in Glenbranter Forest, Argyll, Scotland, using the Nearest Neighbour method (developed by Pepper (1998)), concluded that red deer strip bark from 0.5% to 1% of trees per annum, with the amount of damage varying with tree age (Welch et al. 1987). Areas with high levels of bark stripping were identified as "hot spots" (where bark stripped trees are near neighbours), borne out in that 74% of the plots had no observed damage over a two-year period, while in the same timeframe over 10% of trees were bark stripped on 2% of plots (Welch et al. 1987). The survey by Campbell and Marchbank (2009) in Co. Wicklow reported that 60% of sampled plots had wounded trees and 13% of trees were wounded overall.

Browsing

Browsing is the removal of buds and shoots of the tender, palatable, tips of lateral or leader shoots (Rooney and Hayden 2002). One of the main types of damage to plantation forest is that of leader browsing, which affects the growth and development of the tree (Welch et al. 1991, Welch et al. 1992, Scott et al. 2009). Browsing of the leader shoot of Sitka spruce can cause forking which in turn leads to a reduced mean girth when compared to single stem trees at harvesting (Scott et al. 2009). A browsed leader shoot is shown in Figure 2B.

Browsing by deer on the lateral shoots, however, may not always be harmful to the tree. Few impacts are experienced by trees at low lateral browsing levels (Putman and Moore 1998). Low level lateral browsing can stimulate trees to grow faster, and thus may have a positive impact (Putman and Moore 1998). However, severe lateral browsing can have the effect of stunting the growth of trees, or a crop of trees by a year or more (Welch et al. 1992).

Antler damage

Damage also results from antler abrasions on tree branches and trunks, referred to as thrashing and fraying by antlered male deer (Gill 1992), or species-specific damage such as bole scoring by sika stags (Putman 2000). Thrashing and fraying typically impacts younger trees, while bole scoring by sika stags damages the trunks of mature trees (Putman and Moore 1998).

Potential cost of damage in Ireland

A comprehensive study conducted across eight forest plantations (size range 16.7 to 235.8 ha) in Co. Wicklow modelled the potential loss of income from sika damage in Sitka spruce plantations (Campbell and Marchbank 2009). The deer densities in the study area were estimated at 25–40 km^{-2} primarily using the Faecal Standing Crop method post culling (Campbell and Marchbank (2009). Assumptions in the model included a 2008 value of timber at felling, a typical felling programme of 500 ha, and 50% level of bark stripping based on the estimated sika population present in the areas surveyed. It was observed that 60% of the sampled plots had wounded trees and 13% of the trees were wounded overall. The potential loss of income was estimated at approximately €1,200 ha^{-1}. There is, as yet, no available data from other areas of Ireland with which to compare.

Another Wicklow-based study attempted to determine the loss per hectare in a Sitka spruce crop, when only the bottom 2 m of the tree became devalued due to deer damage (Sweeney and Nieunwenhuis 2008). Under a best case scenario of no damage and no fencing, a return of €10,750.78 ha^{-1} was expected, while a scenario of no damage, with the additional cost of fencing had an expected return of €8,779.19 ha^{-1}. This demonstrated that the cost and maintenance of fencing reduced returns by €1,971.59 ha^{-1}. Under a worst case scenario where a damage level of 71% was recorded and no fencing was used, a loss of €459.83 ha^{-1} would be expected with a return of €10,290.94 ha^{-1} (Sweeney and Nieunwenhuis 2008). This may partially explain why fencing is not widely used in Sitka spruce crops when losses without fencing are approximately one quarter of the overall costs of erecting and maintaining fencing. However, the cost benefit of fencing may differ in broadleaf and other vulnerable crops compared with Sitka spruce.

In Ireland, the direct national output value of forestry (before wages, salaries and profits are taken into account) was about €255.4 million in 2003 (Ní Dhubháin et al. 2009). The National Forest Inventory (Forest Service 2007) recorded data from 2004 to 2006, part of which related to deer damage to commercial conifer and broadleaf trees. This national survey recorded 90.8% of trees with no damage, while 0.5% of trees surveyed were recorded as having been damaged by deer bark stripping. This represents 3,205 trees out of the total of 609,008 trees surveyed for the project. This level of bark stripping in Irish forests concurs with results from a similar local study in Scotland where 0.5–1% of trees were bark stripped *per annum* (Welch et al. 1997). Assuming that (a) all damage recorded by the National Forest Inventory was damage recent to the year in which it was recorded, (b) that the tree becomes unusable once damaged, and (c) that deer damage occurred at a rate of 0.5%, and using the figure of €255.4 million representing direct national output in 2003, then deer damage could potentially cost the Irish economy about €1.3 million per year.

It is clear that the available modelling relating to economic impact of deer in Irish forests is heavily based on inbuilt assumptions and were developed using data obtained from only a few locations in Ireland. Lack of quantitative baseline data from across the country is an impediment to estimating the full cost of deer damage.

Legal status and current control measures of deer in Ireland

Red deer, sika and European fallow deer are protected under the Wildlife Act (1976 (Amended 2000)) in the Republic of Ireland and the 1985 Wildlife Order in Northern Ireland. Deer hunting licences are required from National Parks and Wildlife Service or from the Northern Ireland Environment Agency to hunt deer in each relevant jurisdiction on the island of Ireland. A culling season operates within defined dates. Northern Ireland legislation on deer culling season is regulated under the Deer Act (1991) (UK).

Red deer and fallow deer are listed as species of "Least Concern" in the Irish Red List for mammals and sika were not assessed (Marnell et al. 2009). The IUCN lists red deer, sika, fallow deer and muntjac deer as species of "Least Concern" on an international basis (IUCN 2008). However, in a European context sika and muntjac deer are categorised as "Not Applicable" as they were introduced after 1500 AD (Temple and Terry 2007).

At present, there is no national policy on the management of deer in Ireland (Purser et al. 2009). Deer control in Irish forests is undertaken by recreational deer hunters/stalkers who lease deerstalking rights from Coillte (the semi-state organisation, whose remit is the development of commercial forestry in Ireland) and/or gain permission from landowners to shoot on private land. Deer shooting requires a license from the National Parks and Wildlife Service. A further certificate is required of the deer stalkers who shoot on Coillte leases – the HCAP certificate, which is obtained after successfully passing a written examination and shooting competency test by the Deer Alliance. Deer culls are also conducted by Coillte staff and NPWS staff in their respective areas.

The holder of a NPWS deer licence is required to submit a "bag return" of the number, species and sex of culled deer. These data are then compiled by NPWS at the end of each season. As these are the only figures available within Ireland of "deer numbers" annually culled, they are frequently cited in relation to increases or decreases of various deer populations in different counties and nationally. However, such returns cannot be independently validated, and as such, these annual returns must be interpreted with caution.

Forestry companies may choose to enter into sustainable forest management schemes, such as the Forestry Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification schemes (PEFC). Within Ireland, both of these organisations require management of wild deer (where present) in the forest setting. The FSC requires forest owners and managers to have written deer management plans and to engage with local land owners, stakeholders and statutory authorities, and is designed to be a local or regional deer management plan (FCS 2013). The PEFC requires compliant members to have a written strategy which identifies the management objectives, and also takes account of the relevant licences, including HCAP (PEFC 2013). Both of these are valuable forest managements and accreditation schemes, and recognise the need for deer management, though only at local or regional levels.

Currently there is no national deer management policy, although Coillte recently issued a draft deer-management policy in respect of their estate in which they seek to maintain deer populations at levels to ensure land use objectives are met, while maintaining deer as part of ecosystem biodiversity, but also controlling any expansion of their range (Coillte 2013). A further policy document has been issued by the Inter-Agency Deer Policy Group outlining the need for a national approach to deer management (Inter-agency Deer Policy Group 2011).

Conclusions

Few direct quantitative and qualitative data are available on the impact of deer on commercial forests in Ireland. Most studies rely on small-scale research projects in localised areas and source information from other countries, particularly from the UK. There is evidence that in some cases deer have had an adverse impact on commercial forestry in Ireland, but limited information is available on the actual or potential economic cost to the forestry industry.

Given the reported problems associated with deer in commercial forests and the stated aim of increasing Ireland's forest cover to 17% by 2030 (COFORD 2009), it is not surprising that a national deer management plan has been widely recommended (Inter-agency Deer Policy Group 2011). The lack of quantitative data regarding both deer densities and the scale of the impacts of deer on commercial trees makes the formulation of an effective national management plan aspirational at present. These knowledge gaps need to be addressed.

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Development of improved Sitka spruce for Ireland

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Abstract
Over the past 40 years a significant effort has been made to develop a variety of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) which is specifically adapted to Irish climatic conditions. This has involved selection of the best seed source or provenance, selection of plus-trees, comparative field testing and breeding. The result is an improved variety of Sitka spruce that will provide increased height growth and improved stem form (straightness), but with no loss in wood density (related to timber strength properties). This paper will summarise the work to date in Ireland, how it was carried out, document the benefits of using improved planting stock, and outline what remains to be done.

Keywords: *Plus tree selection, progeny testing, breeding, sexual propagation, vegetative propagation.*

Introduction

The term Tree Improvement refers to the selection and breeding of trees to increase the frequency of certain desired characteristics resulting in an increased economic return over the rotation of the crop. Tree improvement depends on naturally occurring heritable variations in important traits so that selected individuals with different desired traits can be brought together to interbreed to produce new individuals which combine the desired traits of both parents. These changes are permanent and can also provide the basis for further breeding work. Man has been breeding agricultural crops and animals for more than 10,000 years, but tree improvement efforts date back only to the early part of the 20th century. By its nature tree improvement is a slow and expensive process, but despite the considerable up-front investment involved, tree improvement programmes for a range of species around the world have demonstrated a positive return on investment (ROI).

The very legitimate question of "why is it necessary to improve trees?" must be addressed. Data presented in Table 1 shows that naturally occurring forests achieve only about one third of their full productive potential. At least some of this difference can be reduced by planting improved material. Most forest tree species are essentially undomesticated wild populations, with generally more than enough natural genetic variation available to the tree breeder without the need to resort to modern genetic modification (GM) methods.

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Table 1: *Potential and Actual Productivity (Mg equals one metric tonne) of natural forests (From Farnum et al. 1983).*

	Mg ha^{-1}
Theoretical Maximum Potential Net Primary Productivity	55.0
Actual Measured Productivity	18.0
Douglas-fir (*Pseudotsuga menziesii*)	5.7
Loblolly pine (*Pinus taeda*)	3.6

While growth is an important factor, other traits which are also under some degree of genetic control, such as stem form (straightness), branching habit, wood properties, insect and disease resistance and adaptability or survival, can also be improved by breeding. However, not all variation may be due to genetically controlled factors. Some are due to environmental influences, but this variation cannot be used to produce genetic improvements.

Tree improvement programmes consists of two distinct parts. First is breeding to produce improved material and second is propagation of the improved material in large amounts for commercial use. Breeding is necessary for the production of new, improved material whereas propagation produces enough material for it to be used commercially. A review of breeding work with Sitka spruce in Europe has recently been published (Lee at al. 2013). The objective of this paper is to explain the methods that have been used to breed and propagate Sitka spruce (*Picea sitchensis* (Bong.) Carr.), then summarise the results achieved in Ireland over the last 40 years and discuss the work that is currently underway.

Tree improvement methods

What is the source of the inherent genetic variation?

Tree improvement programmes follow a defined sequence of steps in order to take full advantage of the natural genetic variation in the species which is available at several different levels.

- **Species selection** – Different species grow at different rates and require different conditions for optimal productivity. For example, Sitka spruce grows at an average of 16.6 m^3 ha^{-1} year^{-1} in the Coillte estate compared to Norway spruce (*Picea abies* (L.) Karst) which grows at an average of 15.6 m^3 ha^{-1} year^{-1} on similar sites.
- **Provenance selection** – Provenance or the geographic origin of the seed source can have a large effect on subsequent growth and performance. Washington sources of Sitka spruce on average produce one full Yield Class (2 m^3 ha^{-1} year^{-1}) more wood than more northerly sources such as Queen Charlotte Islands (QCI) (Thompson et al. 2005).
- **Parental selection** – Selecting individual or plus-trees that display superior characteristics for the desired traits, is the first step in establishing a breeding programme. The offspring of these parents (progeny) are field tested to select only those plus-trees with the highest genetic quality for use in the breeding programme.

- **Individual selection** – This refers to the selection of the best individuals from a family resulting from the crossing of two superior parents. The progeny from crosses of the same selected parents can be very different due to unique combinations of genes in each individual. There can be as much genetic variation between individuals from the same cross as there can be between different provenances.

To achieve maximum genetic improvement it is necessary to follow the sequence outlined above. For example, selecting superior individuals without first considering the most suitable provenance or parents will not provide the maximum amount of genetic improvement that is possible. It is not always necessary to follow the sequence fully. This depends on the level of improvements required and the resources available. For example, it may only be necessary to identify the best provenance of a species and go no further for species that are of less economic importance, are more difficult to breed or where biological or other constraints exist. Following the full sequence from species to individual selection generally can only be justified for the most commercially important species.

Breeding Sitka spruce

Species testing

Differences in the growth rates of native species, as well as non-native species planted in gardens and arboreta were observed in the 19th century. Species that performed well were considered good candidates for forestry use. Sitka spruce was first planted in Ireland in the 1830s. This species performed very well in those early trials and was established in the plantations of the 1870s and 1880s, but only became a commercially important species in the 1920s (Joyce and OCarroll 2002).

Between 1958 and 1965 the Research Branch of the Forestry Division of the Department of Lands established a series of species trials on a range of suitable afforestation sites around the country. Although these trials had their limitations, Sitka spruce and lodgepole pine (*Pinus contorta* Doug.) were the most successful species both in terms of survival and growth rate across almost all sites. Although other species may have higher growth rates, Sitka spruce is best adapted to the soils and climatic conditions in Ireland and produces a versatile timber.

Provenance testing

The first formal Irish Sitka spruce provenance trial was established in 1960 using commercial seed collections from 10 sources ranging from Alaska to Oregon. This was later followed in the 1970s by a more comprehensive series of IUFRO (International Union of Forest Research Organisation) trials planted on nine different sites across the country consisting of 67 seed sources covering the entire species range from Alaska to northern California. In both provenance trials, the superiority of Washington sources over all others was clear (Thompson et al. 2005), although on low, frost-risk sites along the southern coast of Ireland, Oregon material may be suitable (Thompson 2007).

Figure 1: *An example of a Sitka spruce plus tree selected in Baunreagh property in Mountrath Forest, Co. Laois.*

Plus-tree selection

In the early 1970s, the first efforts towards a Sitka spruce improvement programme began. The original objective was to select and test 1,000 phenotypically superior plus-trees from which the best 10% would be re-selected after field testing based on the performance of the offspring. The re-selected best 100 plus trees would form the basis of the breeding programme. In hindsight this was perhaps too ambitious and it was never achieved.

Plus-trees were selected from above-average yield class stands of Sitka spruce across the country that were between 25 and 35 years-old (Figure 1). Initially the selection intensity was high with only one tree being selected in every 8.5 ha of forest, but later this was reduced to about 1 tree in every 1.7 ha surveyed. This decision was based on work in the Forest Commission in the UK which showed that highly intensive selection of plus-trees did not always result in significantly better gain and that the extra costs associated with the high selection intensity could not be justified (Lee 1999).

Each original plus-tree was assessed against a number of criteria (Table 2) in comparison with the immediately surrounding dominant trees. In later years, wood density was introduced as an additional criterion. In total, only 747 of the originally planned 1,000 plus-trees were selected. Table 3 documents the progress of the plus-tree selection programme between 1973 and 1990.

Table 2: *Criteria used to select Sitka spruce plus-trees.*

Trait	Assessment criteria	
Stem	Straightness	Spiral grain
	Forking	Circularity
	Bends	Drought cracks
	Taper	Resin weep
	Sweep	Epicormic shoots
	Buttressing	Disease (presence)
	Broken leader	
Branching	Branch size	Internodal branching
	Branch length	Branch angle
	Number of whorls	Self pruning
Other traits	Indirect assessment of wood density of plus-tree and several surrounding trees	
	DBH of plus-tree and several surrounding trees	
Overall quality	Plus-trees are rated on a 1 to 10 scale	

Progeny testing

Once the plus-trees were selected, the next step was to test them to identify the best parents, in terms of genetic quality for use in the breeding programme. Climbers were sent to each tree to collect both cones and branch material. The branch material was grafted onto seedling rootstocks to provide a copy of the original plus-tree. Seed was used to grow the offspring or progeny which were planted in field trials on typical Sitka sites. The performance of the progeny gave an indication of the genetic quality of the parent plus-trees.

Progeny tests consisted of a standard design of plots with 8 to 10 trees per row, randomised and replicated four or five times on each site, together with a standard control of imported and unimproved Washington and QCI seed sources against

Table 3: *Year of selection and number of Sitka spruce plus-trees selected for the improvement programme.*

Year selected	Number of plus-trees
1973	39
1976	65
1977	48
1984	236
1985	97
1987	105
1988	57
1989	23
1990	76
Total	747

Table 4: *Summary of Sitka spruce progeny tests.*

Test series	Number of locations	Number of plus-trees	First assessment	Second assessment
1	4	33	1986	1995
2	3	32	1986	1995
3	3	29	1990	1999
4	4	54	1993	2002
5	4	40	1993	2002
6	4	42	1993	2002
7	1	17	1994	2003
8	3	45	1994	2003
9	3	44	1994	2003
10	3	44	1994	2003
11	3	43	1998	2007
12	3	46	1998	2007
13	2	36	1998	2007
Total		505		

which improvements could be measured. The 747 plus-trees were divided into a total of 13 trial series, each of which were planted on two to four different locations around the country (Table 4). Trials were established with 3 year-old transplants and were first assessed after six growing seasons in the field (9 years-old from seed) and again after 15 growing seasons in the field. Of the original 747 plus trees selected, only 505 (68%) were progeny tested for a variety of reasons (e.g. plus tree was felled, no seed was produced, or not enough plants were available for the progeny tests).

Parental selection

After six growing seasons in the field, any plus-tree parents of progeny that were at least 15% taller than a standard Washington control in each trial went forward in the breeding programme (later confirmed in the 15-year assessment). Of the 505 progeny tested plus-trees, only 86 (17% of the original 505 plus-trees tested) were selected based on increased height growth and improved stem form (stem straightness). However, it is known that increased growth rate in Sitka spruce is inversely correlated with wood density, a trait which is well correlated with wood strength properties. As a result, fast grown trees generally tend to have a lower wood density than slower grown trees. Following a further screening of the wood density of the 86 plus-trees, the number of plus-trees that provided increased height growth, improved stem form with no significant loss in wood density, was reduced to 41 (8.1% of the 505 plus-trees tested). These 41 parents formed the basis of the Coillte Sitka improvement programme.

Table 5 provides an example of the results from a typical progeny test, which shows that of the 54 families included in this test, only five were 15% taller than the

Table 5: *Results from a typical Sitka spruce progeny trial containing (half-sibling) progeny collected from 54 plus-trees around Ireland and planted in Coolgreany forest, Co. Wicklow.*

Performance	Number of families
Below Washington control	5
Equal to Washington control	4
Above Washington control	45
10% taller than Washington control	25
15% taller than Washington control	5
20% taller than Washington control	2

Washington control. Thus only these five plus-trees went forward in the breeding programme and all other plus-trees were rejected. While this may seem wasteful, significant genetic improvements will be achieved if only the best individuals enter the breeding programme. Table 5 highlights the fact that selecting the original plus-trees in the forest was not a very precise process.

Under regulations covering the marketing of Forest Reproductive Material in the EU there are four quality grades depending on the degree to testing that has been carried out on this material (Source Identified, Selected, Qualified and Tested). To achieve the category of Tested, the material must have undergone tests in scientifically accepted statistically designed trials compared to a standard seed source. The 86 plus-tree parents discussed above have met the criteria to qualify to be described and marketed as Tested, so all material produced by crosses between them is also considered as Tested.

Breeding

Crosses between individuals are either referred to as open-pollinated or half-sibs, if only the female parent is known and the pollen source is just back-ground material, or as control-pollinated or full-sibs if the identity of both parents are known (the term sib or sibling means offspring or progeny).

As a result of meiosis and subsequent fertilisation, each new individual receives half of its genes from the female parent and half from the male. This recombination of traits from both parents results in a new unique combination of genes which has a large influence on the performance of the offspring, as illustrated in Table 6. Certain parents, such as female 140 and male 56, are known as good general combiners because they tended to produce superior progeny each time they were used in a cross, while other parents produce variable results, such as female 61 and male 125. There were also good specific combinations such as 140 crossed with 2, 140 crossed with 56 and 61 crossed with 56, which produced above average progeny only when crossed with specific parent trees.

It is important to point out that at the time these full-sib controlled crosses were made, progeny test information on the parents was not yet available. When these data became available it turned out that none of these plus-tree parents used in the

Table 6: *Height performance of full-sib crosses of Sitka spruce parents relative to the unimproved Washington control.*

Female Parent	Male Parent		
	2	56	125
48	5.7%	7.4%	8.3%
61	1.2%	16.0%	0.0%
140	21.4%	15.4%	7.4%

crosses in Table 6 were good enough to be included in the breeding programme. Nevertheless, these results show that some of the progeny resulting from crosses between unselected parents can still produce offspring that could be selected for use in a breeding programme (15% or more above control seed lot performance).

The same is true for crosses between selected parents. Table 7 shows the height growth of 34 different full-sib crosses between selected Sitka spruce plus-trees in the breeding programme. Overall, 32 out of the total of 34 crosses were taller than the Washington control, demonstrating the benefit of using selected parents.

Selecting the best individuals from the best crosses

Genetic variation also occurs between different individuals, i.e. siblings resulting from the full-sib cross of the same two parents. Each improved seed derived from a full-sib cross can be vegetatively propagated, producing many copies (clones) of the original individual. Table 8 shows the variation in height growth between 10 clones originating from the same full-sib cross (519 × 547). Two of the 10 clones were 11% taller than the average of all the clones. This demonstrates that within the progeny of each cross there are a certain few that are superior individuals. In this case (Table 8), a further 12% increase in height is possible by using only the two best clones from this full-sib cross. Other similar superior clones from full-sib crosses of other parents could be assembled to produce a clonal mixture that would provide further improvements without sacrificing genetic diversity. These individuals could either be used to establish seed orchards or they could be used to produce material for vegetative propagation.

Production of improved material

The second objective of a tree improvement programme is to ensure that enough of the improved material is available for commercial use. Breeding without large-scale

Table 7: *Field test results of 34 full-sib crosses of selected Sitka spruce parents in Ballynoe Forest, Co. Waterford.*

Performance	Number of Families
Below Washington control	2
Above Washington control	32
5% Taller than Washington control	29
10% Taller than Washington control	24
15% Taller than Washington control	11
20% Taller than Washington control	7

Table 8: *Height growth of 10 clones (A to I) of the full-sib cross 519 × 547 and percentage difference from the clonal average (118.9 cm) in a nursery trial at Kilmacurra (4 tree square plots, randomised and replicated 4 times for 16 plants per clone) after 3 growing seasons.*

Clone	Height (cm)	% above/below average
G	104	−12.5
F	107	−10.0
I	112	−5.8
C	113	−5.0
J	118	−0.7
A, D, H	123	+3.4
B, E	133	+11.8

production of the resulting improved material is of limited commercial value. Improved material can be produced either by sexual or by vegetative propagation methods.

Sexual propagation

The advantage of sexual propagation has already been demonstrated in Table 6. It results in new combinations of genes that may outperform the parents and the process is a relatively simple one. The disadvantage is that crosses between selected good parents will always result in a mixture of both good and poor genetic combinations.

Seed orchards

Seed orchards are designed and managed specifically to produce seed rather than timber and are the main method used to produce improved seed (Figure 2). Sitka

Figure 2: *A young Sitka spruce seed orchard at Ballintemple Nursery, Ardattin, Co. Carlow.*

spruce is slow to flower, and even if sexually mature branches are grafted onto seedling rootstocks, it takes about 10 years for them to produce seed in significant quantities. For a number of reasons, seed orchards typically capture only a part of the genetic improvement that they should be capable of providing. These include contamination by pollen from unselected trees outside the seed orchard, the fact that not all parents flower each year and that some seed may result from selfing (pollen from the parent tree fertilises the seeds of the same tree) which results in poor quality offspring. Some of the combinations between all the flowering parents in a seed orchard also will result in material that is only average or even below average in productivity and quality.

Seed production

Currently Coillte Nurseries produce approximately 28 million Sitka spruce plants per year, which requires the sowing of approximately 165 kilos of seed. Sitka spruce will not begin to flower normally until it is about 20 years-old from seed and good seed crops normally occur on average once every 3 to 7 years. This is due to the fact that a warm, dry period during May and June is required to initiate flower buds which will flower and produce seed the following year. These conditions do not happen very often in this country so good seed crops are infrequent. For this reason, methods have been developed to stimulate flowering of trees in orchards and make seed crops more frequent and reliable.

Flowering is basically a stress response. Studies on flower stimulation in grafted Sitka spruce has shown that a combination of warm temperatures, water stress and the presence of a plant growth regulator, gibberellic acid (GA), which occurs naturally in sexually mature trees, act together to stimulate flowering (Phillipson 1992). While these stress treatments can be applied to large trees in outdoor gene banks or seed orchards, they are more effective when applied under more controllable conditions.

This has led to the development of indoor seed orchards wherein grafts of plus-trees are grown in pots in a greenhouse or polyhouse. Environmental conditions can be modified readily. The plants can be subjected to higher than ambient temperatures, water stress and injected with hormones such as GA to induce flowering. This approach results in a regular supply of both male and female flowers each spring to allow for controlled crosses to be made (Figure 3A). Sitka spruce, like most conifers is monoecious, meaning it can produce both male and female flowers on the same tree which allows the use of selected plus-trees as both male and female parents. Table 9 shows the effect of different treatments on the production of male and female flowers in an indoor potted Sitka spruce seed orchard.

The small size of the trees in the indoor seed orchard however, means that only a limited amount of seed can be produced. While this is adequate for progeny testing of new full-sib crosses, it is not adequate for large-scale production, although this limited amount of valuable material can be multiplied by using vegetative propagation.

Table 9: *Effect of different treatments on flower production in potted grafts of Sitka spruce plus-trees.*

Treatment	Number of male flowers/graft	Number of female flowers/graft
Outdoor potted control	3.0	1.7
Indoor control	14.5	5.6
Indoor + GA 1.0 mg	12.2	16.3
Indoor + GA 1.5 mg	9.8	12.2
Indoor + GA 2.0 mg	17.9	15.4

Vegetative propagation

The advantage of vegetative propagation is that individuals with superior traits can be reproduced exactly (i.e. no genetic variation in the resulting plants). The disadvantage is that the techniques used to vegetatively propagate material results in higher per plant costs than seedlings propagated from seed.

Vegetative propagation techniques include air-layering, grafting, the rooting of cuttings and several tissue culture (micropropagation) techniques. Air-layering is used only in specific cases with certain species. Grafting, although it is widely used in the establishment of clone banks and seed orchards, is too expensive for large-scale propagation. The rooting of cuttings works well with a range of species, especially with juvenile material, and large-scale clonal propagation programmes with forest trees have been in use for many years (Table 10).

However, rooted cuttings typically cost 1.5 times or more to produce than seedlings due mainly to the extra labour required to collect, insert and root cuttings and the capital investment in facilities. Most tissue culture methods have the potential to produce a larger number of plants than is possible with rooted cuttings; however the cost of tissue culture production is still higher due to the increased amount of labour involved. The higher production costs associated with vegetative propagation require that only rare or valuable material can economically be propagated using this approach. Nevertheless, the benefits of clonal planting stock with its uniform growth rates and more uniform products keeps the idea of clonal forestry alive.

Vegetative propagation also allows for the production of the most advanced improved material years earlier than might be possible using seed orchards. As mentioned earlier, a Sitka spruce seed orchard requires at least 10 years after

Table 10: *Clonal plantations worldwide (Kellison 2004).*

Species	Area (000 ha)
Conifers	5,080
Poplars	1,567
Eucalyptus	1,217
Other broadleaves	22
Total	7,886

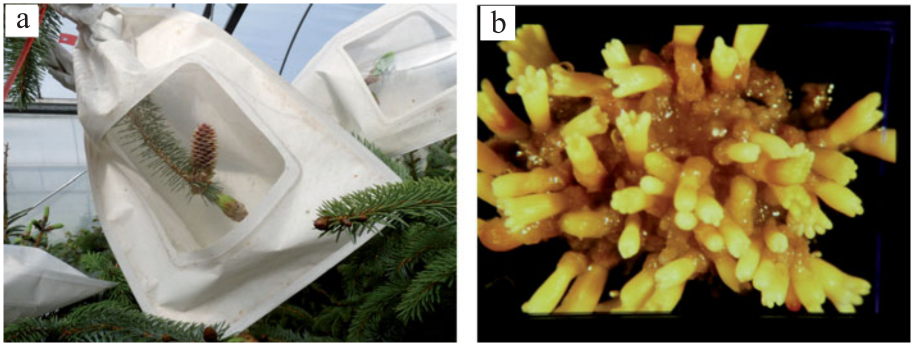

Figure 3: *Female Sitka spruce flowers in an isolation bag to produce a full-sib cross between two selected parents (a) and somatic embryos of Sitka spruce produced in the laboratory (b).*

establishment to come into full production, whereas the latest improved material from an ongoing breeding programme could be available in only 3 to 5 years. There is no delay due to a lack of flowering if vegetative propagation methods are used.

The small amount of valuable seed from the full-sib crosses in indoor seed orchards can be increased using vegetative methods to produce commercial-scale amounts of planting stock. The most effective way to do this is by a tissue culture process known as somatic embryogenesis (SE). In this process an immature seed is used to establish special cells of that individual which are then grown on in a Petri dish in the laboratory. The unorganised cells are multiplied to produce large amounts of this tissue in a relatively short time. When enough material is available, the culture conditions can be changed and the unorganised cells can be induced to mimic the process that takes place in the developing seed, to form complete embryos similar to those formed in seeds (Figure 3B). The advantage of SE over other tissue culture propagation methods is the large number of plants that can be produced very quickly with a minimal amount of handling on a year-round basis.

Due to the amount of labour required to produce plants by SE, the current cost per plant is currently about 10 times that of a seed-produced plant and as such it would not be economic to establish a plantation with SE plants, except for research purposes. Work is underway around the world to reduce production costs by automating the process or by producing artificial seeds. Nevertheless, the fact that SE can produce a larger number of copies of an individual faster than any other method has led to the use of SE to establish stock plant hedges of Sitka spruce (Figure 4A) from which cuttings can be collected, rooted (Figure 4B), transplanted into a nursery bed and eventually planted in the field. Once established, a Sitka spruce stock plant can produce up to 50 cuttings per year over a 5- to 6-year period, so the high cost of the original SE stock plant is reduced when it is spread over all of the cuttings it produces over its lifetime. The resulting two year-old Sitka spruce rooted cutting is equal in height and root collar diameter to a three year-old seedling transplant and it provides improved planting stock quickly without the delay associated with the seed orchard approach.

Parent trees from the Coillte Sitka improvement programme are currently

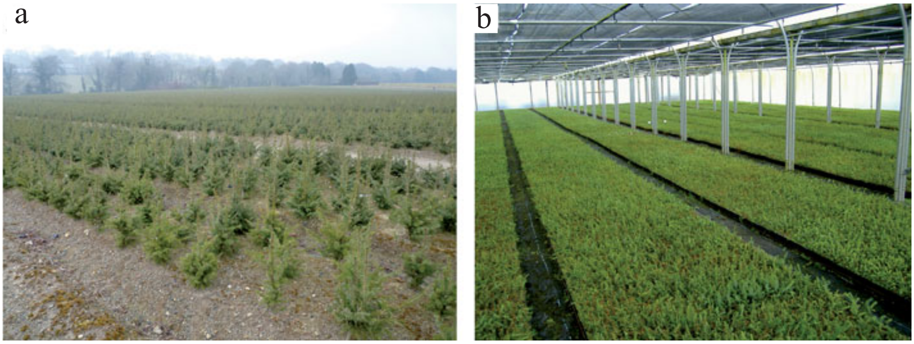

Figure 4: *A hedge or cutting orchard of Sitka spruce to provide cuttings for rooting at the Coillte Nursery at Clone near Aughrim, Co. Wicklow (a) and Sitka spruce cuttings being rooted in a tunnel at the Coillte Nursery at Clone near Aughrim. Co. Wicklow (b).*

crossed and the resulting seed used to produce SE stock plants from which cuttings are taken and rooted to provide commercial amounts of improved planting stock in Ireland. In the initial propagation stages, the genetic identity of each plant is maintained and observed for any irregularities, but once the material is established in a hedge orchard, clonal identities are no longer retained. In this way the genetic diversity of the rooted cuttings can be kept as wide as possible, and the resulting crops are likely to be more resilient over the length of the rotation. Currently Coillte produces about 2.5 to 3.0 million rooted cuttings of improved Sitka spruce per year. This material is commonly referred to as rooted cuttings, cuttings, vegetatively propagated, veg prop or VP planting stock.

Economics and performance of improved material

A series of demonstration/experimental trials comparing unimproved Washington and improved Sitka spruce produced by rooted cuttings were established in the 1990s. The results from two of the trials are presented in Table 11, which shows that the improved Sitka spruce produced about 25% more wood volume than the unimproved Washington material after 14 growing seasons in the field. The increased volume production is the result of the selection for increased growth, together with selection for lighter branching.

As discussed earlier, improved rooted cuttings cost more than unimproved Washington Sitka spruce seedlings. For this reason, combined with the fact that only limited amounts of the improved rooted cuttings are available, it is recommended to plant the rooted cuttings in mixture with unimproved seedling material. The results

Table 11: *Increased productivity of improved vegetatively propagated plants over unimproved Washington Sitka spruce seedlings after 14 growing seasons in the field.*

Source	Height (m)	DBH (cm)	Volume ($m^3 ha^{-1}$)	% volume increase
Unimproved Washington	12.3	15.7	207	--
Vegetatively propagated	13.1	17.1	262	26.5

of an economic analysis of the discounted benefit of increasing volume production of the improved rooted cuttings over the full rotation of the crop showed that a 50/50 improved rooted cuttings/unimproved Washington Sitka seedling crop would more than pay for the extra cost of the rooted cutting material (Phillips and Thompson 2010). Although the cost of the plant material (both improved rooted cuttings and unimproved seedlings) has increased since the 2010 analysis, the result is the same using current costs.

In addition, there are other benefits to planting improved rooted cuttings which are more difficult to quantify. These include faster exploitation of site resources, thus minimising or eliminating the cost of vegetation control treatment, significant improvement in stem straightness and reduction in forking, significant improvement in branching (fewer and smaller branches) while at the same time causing no significant reduction in wood density. Improved Sitka spruce will also sequester carbon more quickly than unimproved material.

Conclusions

The work discussed in this paper summarises the results achieved over the last 40 years on improving Sitka spruce in Ireland. While similar work has been done with QCI Sitka spruce in the UK, the Irish programme is based mainly on more productive Washington material which has been selected and tested under Irish climatic conditions. In retrospect, the same progress could have been achieved in a shorter period of time, but limitations in funding and manpower delayed the production of improved material.

Improved Sitka material from the Coillte tree improvement programme is currently only available as rooted cuttings, but in time (5 to 10 years) it will also be available from recently established seed orchards, which will increase the availability of improved planting stock. Nevertheless, with an active Sitka spruce breeding programme, the most advanced and best quality material will always be available first from the veg prop programme because of the delay of seed production in seed orchards.

Perhaps the greatest obstacle facing the use of the improved Sitka spruce material is the extra cost of the planting stock. While higher up-front investment costs involved in producing improved planting stock has impeded planting of improved rooted cuttings, an economic analysis has shown conclusively that the higher initial costs are more than offset by the increased timber volumes produced over the rotation (Phillips and Thompson 2010).

Tree improvement is a cumulative process in which further improvements are added to those accomplished in the past. The current programme has focussed on volume production and wood quality to produce high quality structural timber. Breeding for other traits such as branching habit, other wood properties or disease or insect resistance is also possible. Time is perhaps the greatest limiting factor in tree improvement and efforts to make tree improvement more efficient (shorten the testing period) and effective (using morphological, physiological or molecular "markers") are currently underway in the DAFM-funded ForGen research programme.

In addition, as shown in Table 8, the use of clonal material can further improve the productivity and quality as well as providing a more uniform crop to manage and a more uniform product for processing. Sitka spruce is a species that lends itself very well to clonal propagation, but there are genuine concerns about the potential risks of reduced genetic diversity in clonal plantations which can be addressed. The economics and public acceptance of clonal forestry will determine whether it has a commercial application or not.

Practical implications

- The use of improved material offers a permanent way to increase the productivity and quality of new forest plantations.
- Improved Sitka spruce has been developed specifically for Irish conditions that provide increased growth, improved stem form with no loss in wood quality.
- The improved productivity and quality of the resulting crop will more than offset the higher cost of improved planting stock.

Acknowledgements
This paper is dedicated to all the researchers and foresters who contributed to the Irish Sitka spruce tree improvement programme over the past 40 years.

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Transformation to continuous cover forestry: a review

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Abstract

Continuous cover forestry (CCF) is an approach to forest management that is gaining increasing attention. Although not a new concept, a number of developments have prompted a renewed consideration of this approach. These have centred on societal concerns about the negative impacts of clearfelling as well as broader societal expectations of multi-purpose management of forests. With renewed interest in CCF, the process of transforming even-aged stands that are currently managed under the clear-cut system to CCF has begun in a number of countries.

The objective of this paper is to present a review of the scientific literature on transformation to CCF. The review is organised according to a series of questions that address the issue of transformation; i.e. where and when is it appropriate to consider transformation; how long does the transformation process take; and what are the drivers to transformation. The review concludes with a brief overview of existing long-term transformation trials in the UK.

The review of the literature identified that there was a limited number of papers on the topic of transformation and most of these emanated from the UK and Central Europe. For this reason the review was expanded to include literature on the starting point and end result of transformation which is typically (although not exclusively) an even-aged (regular) structure and an uneven-aged (irregular) structure respectively. The most common themes in the transformation literature concerned the structure of stands being transformed and the initial stages of the transformation process.

Keywords: *Silvicultural systems, stand structure, economics, stability, biodiversity, climate change.*

Introduction

Continuous cover forestry (CCF) is not a silvicultural system in itself (Yorke 1998). Instead it involves the use of silvicultural systems whereby the forest canopy is maintained at one or more levels without clearfelling (Forestry Commission 1998). More restrictive definitions of CCF are often used. Von Gadow (2001, p. 2) for example indicates that CCF is "the use of systems that are characterized by selective harvesting; the stand age is undefined and forest development does not follow a cyclic harvest-and-regeneration pattern".

The current consideration of CCF continues the debate which emerged at the end of the 19th century in Central Europe about the relative merits of regular and irregular silviculture (Mason et al. 1999). At that time Europe had just gone through a period of industrialisation and population growth. Demand for timber increased

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and unregulated selection fellings led to the overuse and uncontrolled exploitation of forests (Pommerening and Murphy 2004, Schütz et al. 2012). In response, a very rigid approach to silviculture and management evolved (Matthews 1989). Even-aged plantations, often of Norway spruce (*Picea abies* (L.) Karst.) and Scots pine (*Pinus sylvestris* L.), were established and managed under the clear-cut system throughout Europe with the aim of quickly restoring forest cover (Hanewinkel 2009) and ensuring that large quantities of wood were produced (Schütz et al. 2012). However, it was not long before these plantation forests began to suffer wind damage (Hanewinkel 2009) prompting some European foresters to move towards "more flexible methods of silviculture and management" and towards more irregular forms of forest stands (Matthews 1989, p. 11). The term "continuous forest" (*Dauerwald*) was introduced by a German forester, Möller, at the beginning of the 20th century (Möller 1922) with the principles of avoiding clearfelling to maintain forest conditions and of abandoning the concepts of age-class and rotation (Helliwell 1997). For the first half of the 20th century Swiss foresters attempted to implement the selection system in almost all forests (Schütz 1999). However, the clear-cut system continued to be widely used throughout Germany and France as forest authorities resisted the use of the selection system fearing it would lead to uncontrolled exploitation similar to that witnessed previously (O'Hara et al. 2007).

The use of the clear-cut system was widespread in Europe throughout much of the 20th century, with an associated decline in interest in CCF (Pommerening and Murphy 2004). However, in the 1980s and 1990s alternative silvicultural systems to clearfell attracted renewed consideration. There were a number of drivers that emerged concurrently at international level to stimulate this interest. First, there were societal concerns about clearfelling which focussed on the negative visual impacts (Mason 2007). There was increasing acceptance of the multi-functional forest paradigm and a belief that alternative approaches to clearfell would be better able to deliver on this forestry model (Mason et al. 1999). Following the UNCED Summit in Rio in 1992, one of the aims of forest policies worldwide was to increase the structural and species diversity of forests and CCF was considered a means of achieving greater diversity (Mason 2007). The societal concerns about clearfelling and the changing expectations of the functions of forests coincided with a decline in the health of second and third generation Norway spruce stands in Central Europe (Hasenauer 2004). The continued instability of these stands was highlighted when they suffered extensive wind damage during a number of catastrophic wind storms (Kenk and Guehne 2001). A strategy was adopted to convert these pure conifer plantations to mixed stands. This process also involved a change in the stand structure from regular, even-aged to more irregular, uneven-aged (aka "transformation") (Hanewinkel 2001) with a "heavy emphasis on continuous high forest cover and rich structural diversity" (von Lüpke et al. 2004, p.123). Thus, within Europe CCF began to be considered as a suitable approach to forest management. In Ireland, interest in CCF has also developed and the reasons for this and an overview of the current situation regarding the practice of CCF in Ireland are outlined in detail in Vítková et al. (2013; this issue).

Silvicultural systems that deliver CCF

There are a number of high forest silvicultural systems that can be used to implement CCF including the shelterwood systems (uniform, group, strip and irregular), and the selection systems (group and single-tree) (Figure 1). These systems generally rely on natural regeneration, although planting is used where a different provenance or species is required.

The key difference between all the aforementioned systems and the clear-cutting system is that in the latter, entire coupes are felled and usually regenerated artificially, while some element of canopy cover is retained in the other systems. In shelterwood systems the old stand is removed in a series of regeneration fellings, while in selection systems single trees (or small groups) are removed throughout the forest (Smith et al. 1997). Forests managed under the selection system are often referred to as *Plenterwald* forests.

Categorising high forest silvicultural systems as shelterwood and selection systems as outlined above is quite common. However, another approach relates to the resultant forest structure, i.e. even-aged silvicultural systems versus uneven-aged systems. Often CCF is associated with uneven-aged silviculture; however, the more inclusive definition of CCF used by the Forestry Commission in Great Britain means that even-aged stands that are produced using the uniform shelterwood system, for example, would also be considered CCF. The term irregular silviculture/silvicultural system is also used as a synonym for uneven-aged silviculture, with Helliwell and Wilson (2012) describing both as leading to forests

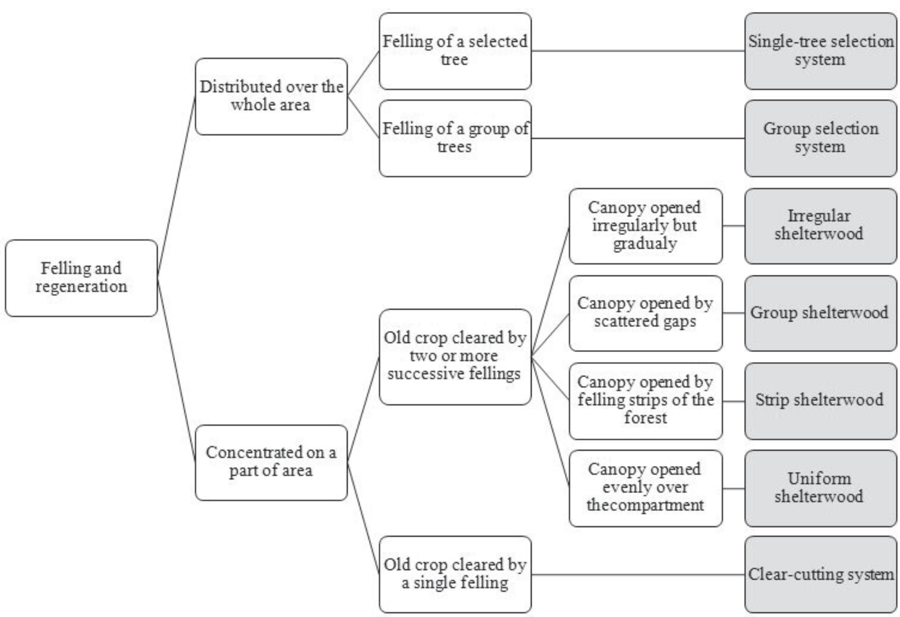

Figure 1: *A classification of high forest silvicultural systems adapted from Matthews (1989).*

with at least three size classes intimately mixed. The systems also vary according to the degree of canopy influence with the clear-cutting system having the least, the shelterwood systems providing canopy protection during establishment and early growth of seedlings, while the selection systems are characterised by the dominance of canopy influence throughout the life of the stand (Coates and Burton 1997). Coates and Burton (1997) further suggest that silvicultural systems can be classified into two groups based on the distribution of canopy trees after harvest; the first group includes systems where canopy trees are evenly distributed after harvest (i.e. uniform shelterwood, single-tree selection); the second group create gaps in the tree canopy (i.e. group, irregular and strip shelterwood and group selection). They argue that the measurements of gap size and gap dispersion are means of describing any silvicultural system along a continuum. O'Hara et al. (1994) further support the view that silvicultural systems can be viewed as structural gradients from clear-cut to single tree selection system.

In the context of the renewed interest in CCF and in transforming even-aged stands, it is timely to examine the research that has been conducted on the topic of transformation. Hence the objective of this paper is to present a review of the scientific literature on transformation to CCF. The literature review is organised into sub-sections addressing some key questions relating to transformation, i.e. where and when it is appropriate to consider transformation; how long the transformation process may take; and the reasons as to why forest owners opt to transform their stands. A review of some existing long-term transformation trials is also presented. The approach used to gather information for the review is also described.

Methods

To identify relevant papers for this review, Google Scholar, Scopus and EBSCO Host Premier Search were used to search for original studies in peer-reviewed journals. Books, newsletters, research reports and research information notes relevant to the topic were also included in the review. The search was conducted using primary keywords (Table 1) and their combinations. In addition, the combinations of individual primary keywords and individual secondary keywords (Table 1) were used.

Transformation to continuous cover forestry

What is transformation?

Transformation describes the process of changing an even-aged stand, typically managed under the clear-cut system to CCF management. It involves the gradual change of forest structure (Pommerening 2006), typically from one that is very simple and homogenous to one that is highly variable and with many complex interactions (O'Hara 2001). Mason and Kerr (2004) allow for the possibility that the outcome of transformation may be a simple structure with only one or two canopy layers. Occasionally the term conversion is used interchangeably with transformation (e.g. Hale et al. 2004); however, conversion can involve a rapid

Table 1: *A list of primary and secondary keywords used when searching for papers for the current literature review.*

Primary keywords	Secondary keywords
Continuous cover forestry	History
Transformation	Wind
Uneven-aged silviculture/forests/structure	Stability
Irregular silviculture/forests/structure	Biodiversity
Alternatives to clearfell/clear-cutting/clear-cut	Recreation
Near-nature forestry	Economics
Close-to-nature forestry	Climate change
Selection system	
Group selection system	
Group shelterwood	
Uniform shelterwood	
Irregular shelterwood	
Strip shelterwood	
Plenterwald	
Clearfelling	
Silvicultural systems	

change in forest structure (von Lüpke et al. 2004); hence transformation is considered a special form of conversion (Hasenauer 2004).

Oliver and Larson (1996) defined stages of stand development that are often used as a model of how a "natural even-aged" stand might naturally transform (O'Hara 2001) to a more irregular (multi-cohort) structure over time:

- Stand initiation – after a disturbance, new individuals of a species continue to appear for several years.
- Stem exclusion – after several years, new individuals do not appear and some of the existing ones die. The surviving ones grow larger and differ in height and diameter; first one species and then another may appear to dominate the stand.
- Understory re-initiation – later, forest floor herbs and shrubs and advanced regeneration again appear and survive in the understory, although they grow very little.
- Old growth stage – much later, overstory trees die in an irregular fashion, and some of the understory trees begin growing into the overstory.

In natural even-aged stands, the understory re-initiation phase may emerge as tree mortality in the overstory provides the growing space for a new cohort to develop through natural regeneration (O'Hara 2001). Transformation can therefore be described as an acceleration of natural development (such as that outlined above) to achieve the desired forest structure (Malcolm et al. 2001).

Where is transformation appropriate?
In outlining where transformation is appropriate it is important to take into account location as well as site factors. Yorke (1998) identified locations where CCF (and hence transformation) is desirable as those:

- with high landscape value;
- used for recreation purposes;
- in close proximity to towns;
- with environmental protection designations;
- where restocking after clearfell would prove uneconomic.

The size of the stand should not be a limiting factor as studies in Europe have shown that transformation can be applied on a large scale as well as on properties only a few hectares in size (Schütz 2001). Nevertheless, it is generally agreed that applying transformation is only possible in areas with suitable conditions for the desired management including:

- an overstory of the desired species and genetic quality (Mason and Kerr 2004);
- the presence of natural regeneration of a desired species (Yorke 1998, Malcolm et al. 2001, Mason and Kerr 2004);
- suitable light conditions at ground level (Malcolm et al. 2001);
- absence of competing vegetation to the natural regeneration (Yorke 1998, Mason and Kerr 2004);
- absence of browsing of advance regeneration and of seeds and cones (Mason and Kerr 2004);
- low to moderate windthrow hazard (Yorke 1998, Mason and Kerr 2004).

When is it appropriate to transform?
Transformation that is initiated early is most likely to be successful since tree stability declines as an even-aged stand develops at a high density (Cremer et al. 1982). Stability is a key issue as the transformation process will inevitably open up the stand and release individual stems, thereby increasing the risk of windthrow. For this reason Hale et al. (2004) recommend that transformation be initiated at pole stage. Starting transformation in older stands depends on the features of the given stand, i.e. thinning history, soil type and the rooting depth (Mason and Kerr 2004); however, on exposed sites the risk of windthrow may be so great in these stands that it may not be practical to transform them (Hale et al. 2004).

Adequate natural regeneration is the main requirement to ensure successful transformation once stand stability has been achieved (Schütz 2001). The age when the stand begins to produce good quantities of seed is therefore of great relevance to the process (Malcolm et al. 2001). Although some tree species such as Scots pine, lodgepole pine (*Pinus contorta* Doug.) and European larch (*Larix decidua* Mill.) start bearing seeds early, the best seed crops are unlikely to be produced until about 10–20 years later (Savill 2013) (Table 2). However, enrichment planting may be used if the stand is too young or a different species is desired (Matthews 1989).

Suitable light levels are required for successful natural regeneration and for the successful progress of transformation. Hale (2004) identified the understory light

Table 2: *Earliest and best age for seed bearing for major commercial species, adapted from Savill (2013).*

Species	Earliest age for seed bearing (years)	Best age for seed bearing (years)
Scots pine	10–20	>60
Lodgepole pine	10–20	30–40
Norway spruce	30–35	50–60
Sitka spruce (*Picea sitchensis* (Bong.) Carr.)	30–40	>50
European silver fir (*Abies alba* Mill.)	25–30	40–60
Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)	30–35	50–60
Western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)	20–30	40–60
European larch	20–30	40–60
Oak (*Quercus* spp.)	40–50	>80
Sycamore (*Acer pseudoplatanus* L.)	25–30	40–60
European beech (*Fagus sylvatica* L.)	50–60	>80
Ash (*Fraxinus excelsior* L.)	25–30	40–60

and associated stand basal area values required for successful seedling regeneration and growth of some commercial conifer species:

- light demanding: larch (>40% light[1], ~20 $m^2\ ha^{-1}$) and Scots pine (35% light, ~25 $m^2\ ha^{-1}$);
- intermediate: Sitka spruce (20% light, ~30 $m^2\ ha^{-1}$) Douglas-fir (15% light, ~35 $m^2\ ha^{-1}$);
- shade tolerant: western hemlock (10% light, ~40 $m^2\ ha^{-1}$).

The importance of thinning in the transformation process

O'Hara (2001) proposed that the first step in the transformation process should mimic the understory re-initiation phase of Oliver and Larson's (1996) model of stand development, shown earlier, by promoting a new cohort of trees. However, in windy climates, transformation will have to start earlier with the aim of promoting stability in the stand. Thinning regimes are therefore key elements in the transformation process (Schütz 1997; cited in Mason 2002) and in stands being transformed thinnings should start earlier and be heavier than normal (Mason and Kerr 2004). This will promote crown (essential for future seed production) and root development along with greater diameter increment, the combination of which should increase stability. Heavier thinning will also be required to ensure that the critical values of stand basal area necessary for successful regeneration to occur.

Low thinning (thinning from below) is commonly used in coniferous plantations and it involves the removal of most of the subdominant and suppressed trees. However, it is expected that there will be an increased use of crown thinning

[1] Percentage of incident light transmitted through the canopy.

(thinning from above) in stands being transformed to and/or managed under CCF (Mason and Kerr 2004). Crown thinning favours the early selection of better quality trees, i.e. frame trees (sometimes referred to as final crop trees, target trees, Z-trees, future trees or elite trees), by removing competing stems thereby encouraging growth of the selected trees (Cameron 2002). Frame trees are selected on the basis of the following desirable properties: straight stem, light branching, good vigour, no visible damage or defects and healthy foliage. During the thinning operation, one to three of their competitors are removed. The number of frame trees per hectare is determined by the final size of the trees. Davies et al. (2008) provide a guide to the number of frame trees according to species and the target diameter. They indicate that for a target diameter of 60 cm, the number of frame trees varies from 68 for ash to 247 for western red cedar (*Thuja plicata* Don ex D.Don). In general, it is recommended that frame trees are pruned to increase their quality and secure better financial return. The remaining trees in the forest (non-frame trees) are sometimes referred to as "matrix trees" that are meant to support the frame trees.

Graduated density thinning (GDT) is a thinning pattern currently being used in the process of transforming young stands to CCF management in a number of private forests in Wales and Ireland. It was developed by a Latvian-born forester, Tallis Kalnars, and applied by him in a number of woodland estates in Wales that were undergoing a transformation process in the 1980s. During the first thinning, the racks are cut in every eighth row and 40% of trees from the row immediately adjacent to the rack are removed. In the second row from the rack, 20% of the trees are removed and 10% of the trees are removed from the third row (Figure 2a). The fourth row, which is situated half way between the racks, remains intact (Davies 2009). This unthinned centre row is considered to be a stabiliser row acting as a risk management tool mitigating the risk of windblow (Morgan pers comm). Selection of

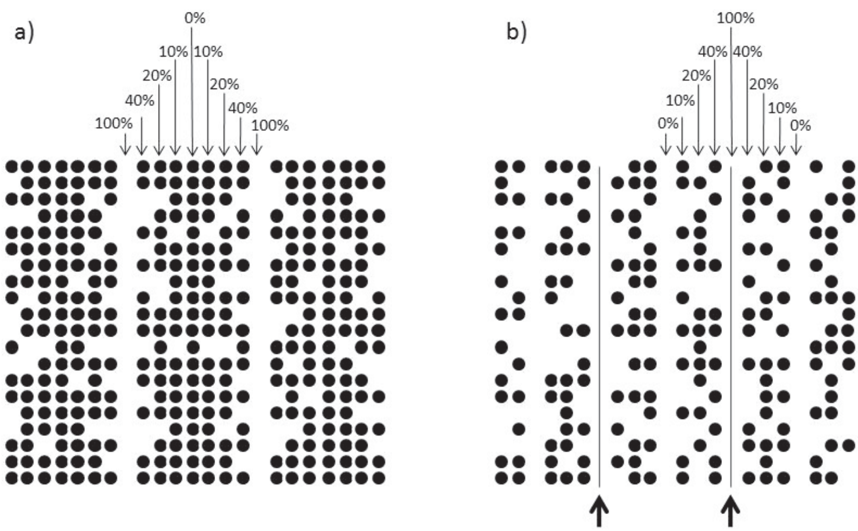

Figure 2: a) *a pattern of graduated density thinning during the first intervention; b) a pattern of graduated density thinning during the second intervention.*

the trees to be removed is based on quality. In the next thinning, the intact rows are removed to make new racks, the previous racks abandoned, with further selective thinning taking place on either side of the new rack according to the given intensity (Figure 2b). The permanent racks are chosen during the third thinning intervention. The number of interventions that follow the pattern outlined varies according to the site and stand. Typically crown thinning or target diameter thinning follows. The proponents of the system claim that it leads to a more stable stand and one that is structurally diverse. As it also involves a systematic removal in both the first and second thinning it is considered to provide higher early thinning returns than conventional thinning (Morgan pers. comm.). The validity of these claims is currently being tested in a thinning experiment set up in 2010 in two Sitka spruce stands in Ireland, which is expected to provide meaningful results in the near future.

Graduated density thinning should not be confused with variable density thinning (VDT), another thinning pattern that has a tradition of use in uneven-aged forests in Central Europe (e.g. Schütz 2001; cited in Pukkala et al. 2011). It involves thinning a forest at different intensities in patches of approximately 0.1 to 0.5 ha (Ibid.). This leads to greater structural heterogeneity in the forests (Aukema and Carey 2008).

An important silvicultural tool that is frequently used during the process of transformation to CCF is target diameter harvesting. This may follow a number of thinning interventions. It involves the removal of stems that have reached a certain minimum (target) diameter (Tarp et al. 2005). By removing these larger trees, the smaller trees are released from competition and are given more growing space. Sterba and Zingg (2001) used target diameter harvesting in the conversion of a Norway spruce stand in Austria and found that the smaller trees reacted well to the crown release and made efficient use of the stand area gained. This practice diversifies the tree sizes throughout the forest stands and improves stability, which are important aspects when CCF management is applied.

When is transformation complete?

The transformation process is relatively new, particularly in the UK and Ireland. Forest managers in these countries will therefore need guidance as to how to identify when transformation is complete and how to manage the transformed stand in the long term. The desired output of many (although not all) transformation processes is an irregular stand structure. Cameron and Hands (2010) outline four basic characteristics describing the 'balanced state' of an irregular stand:

- the shape of the diameter distribution should follow an approximate negative exponential relationship (reverse-J curve) (see Figure 3);
- the stand increment should remain more or less the same from one harvesting intervention to the next (Meyer 1952);
- the relative consistency of stocking density and basal area between harvesting interventions;
- the requirement for sufficient natural regeneration of the appropriate species (Sterba 2004) and for adequate recruitment of saplings into the smallest measurable diameter classes to maintain the diameter distribution (Meyer 1952).

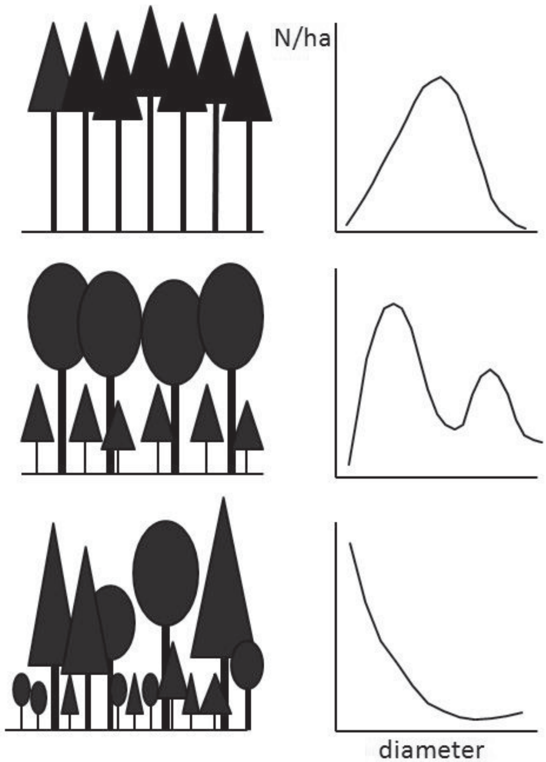

Figure 3: *Forest stand structure with appropriate diameter distribution showing an even-aged structure on the top (uni-modal diameter distribution, e.g. even-aged plantation), uneven-aged with two ages in the middle (bi-modal diameter distribution of two-storied forest, e.g. uniform shelterwood) and uneven-aged with numerous ages on the bottom ('reversed-J curve' diameter distribution, e.g. group selection system).*

The diameter distribution in a stand that exhibits a negative exponential shape is one where "each diameter class has fewer stems than the adjoining smaller diameter class" (Matthews 1989, p. 167) with the ratio between the number of trees in one diameter class to the number in the next larger class being a constant, referred to as the q factor (Kerr 2001). Such a distribution is often referred to as a reverse-J diameter distribution (Figure 3). This feature can be used by forest managers to guide felling during the transformation process and is commonly used to guide management in uneven-aged stands. The actual structure of the stand is compared to an idealised reverse-J curve and the difference between the two is used to decide the number and size of trees to be removed (Ibid). In North America, the q factor was adopted as the primary method of stocking regulation in uneven-aged stands (O'Hara 1998). Yet O'Hara (2001, p. 84) cautioned that uneven-aged stands need not always follow the perfect reverse-J-diameter distribution to gain diverse structure and that the "notion of balanced uneven-aged stands appears to be little more than an attempt to inflict arbitrary human values to ecological systems". Kerr

(2001) also acknowledges that it is not the only way to manage uneven-aged stands but nevertheless he has used it to assess progress in a long-term transformation trial (Kerr et al. 2010) arguing that it is relatively easy to understand and implement (Kerr 2001).

In balanced stands, stand increment should remain more or less the same from one harvesting intervention to the next (Meyer 1952). This equilibrium stand increment, more commonly referred to as equilibrium growing stock, is represented in terms of the volume (m^3 ha^{-1}) across broad DBH categories (Ibid). This feature can be used by forest managers to assess the progress of transformation (Poore 2007) and to guide the long-term management of the transformed stands. For example, in the lowland European silver fir, Norway spruce and European beech selection forests in Switzerland, the equilibrium growing stock is described as 20% volume in the 16–32 cm diameter class; 30% in the 33–52 cm diameter class and 50% in the >52 cm diameter class (Poore 2007). These values act as targets for management in these stands and harvesting is guided by them. The equilibrium growing stock will vary according to the species composition and site with more fertile and sheltered sites having a higher proportion of large trees (Ibid.). Consequently the target percentage per diameter class can vary from 21/22/57 to 21/37/42 for various sites in the Swiss Juras (Schütz 1989). To date there is no information on the equilibrium growing stock for any of the commercial tree species in Ireland and UK, hence further work would be needed if such an approach were to be used to guide management in transformed stands in these countries (Kerr 2001).

Transformation from a regular to a fully irregular structure can take more than 100 years (Schütz 2001). Transformation in the Glentress trial (see below) was originally expected to take 60 years; this has now been revised to 90 years (Wilson 2013). Kenk and Guehne (2001) indicate that the period involved in transformation can range from 20–60 years. Ultimately the time required to achieve successful transformation varies according to the desired structure with transformation to a two-story stand likely to take a much shorter period than to a fully irregular stand. Wilson (2013) noted that much work in transforming stands is adaptive without a clearly defined end point.

Why transform?

In a previous section, the locations and sites which would be suited to transformation have been outlined. Ultimately the decision to transform a stand will be determined by the objectives of the forest owner. Throughout Europe forest authorities are choosing to transform stands in the belief that CCF will lead to greater stability. There is also an assumption that greater biodiversity and amenity will be associated with CCF. Other forest owners are opting to transform stands for economic reasons. It has also been suggested that stands managed under CCF will be more resilient to the effects of climate change. In this section these issues will be explored. As research on the transformation process per se is quite limited, this section will include comparisons between the starting point and end result of transformation which are assumed to be an even-aged (regular) structure and an uneven-aged (irregular) structure, respectively. It is acknowledged that in reality both the start and end points of transformation may lie somewhere in between these extremes.

Stability in CCF stands

A key driver to the move from even-aged stands to uneven-aged stands in Central Europe was the high levels of windthrow experienced in the former. Lanier (1994), for example, found that the windblown volume in regular stands amounted to 150% of the annual cut compared to 15% in selection forests following a storm in 1967 in Switzerland. More recently Dvorak et al. (2001) found significantly lower wind damage levels in irregular stands compared to regular stands after the storm Lothar in Switzerland in 1999. von Lüpke and Spellman (1999) claimed that diversification of species within a stand lowers its susceptibility to various natural hazards, including wind, since individual tree species respond differently to hazards due to their varying morphology. Furthermore diversity in size is also important with Otto (2000) noting that although extensive damage to both regular and irregular stands occurred in 1972 in lower Saxony, the understory of the irregular stands remained largely undisturbed. Yorke (1998) similarly noted that storm damage in uneven-aged forests tends to occur on the tallest trees with the remaining size classes staying intact. In reviewing studies on the relative stability of irregular stands, Mason (2002 p. 348) explained that many comparisons are confounded by the effects of site which led him to conclude that "it is still unclear whether irregular stands will be less, similarly, or more vulnerable to wind" in the UK. Nevertheless, studies conducted in wind tunnels have confirmed that the presence of smaller sub-canopy trees reduces the loading on the main canopy trees by providing support and absorption of energy from the canopy-penetrating gusts (Gardiner et al. 2005).

While the end result of the process of transformation may be a more windfirm stand, the process of transformation in itself may create an unstable stand. Such concerns led Yorke (1998) and Mason and Kerr (2004) to recommend that transformation should only be considered in windfirm sites as inevitably older, taller trees will be exposed during the transformation process. However, the timing and approach used to the initial thinning during transformation, i.e. earlier and heavier, should promote stability.

Biodiversity and recreation

Since a drive toward increased biodiversity partly explains the increased interest in CCF it is important to consider whether there are data to support this assertion. Stokes and Kerr (2009) note that the use of CCF will lead to:

- extended rotation lengths and older trees;
- greater diversity of vertical structure;
- a greater mix of species;
- increased spatial heterogeneity at the landscape level if harvesting occurs at a range of scales.

Older stands have greater structural diversity (Peterken et al. 1992) which is shown to be associated with greater biodiversity (Aukema and Carey 2008). Similarly greater spatial heterogeneity is associated with higher biodiversity levels

(Churchill et al. 2013). Hence Stokes and Kerr (2009) conclude that there is evidence that the factors associated with CCF will help maintain and enhance biodiversity. However, they caution that the benefits will depend on the nature of the woodland and its position in the landscape.

Biodiversity levels in different silvicultural systems were compared in a number of studies. For example, Légaré et al. (2011) compared beetle biodiversity in Canadian forests where selection cutting, irregular shelterwood and clear-cut (using protection of advanced regeneration and soil) had been applied. An old-growth irregular stand was used as the control. Beetle communities were highest and similar in the selective cutting treatment and the control, a finding attributed to the higher volume of deadwood in these treatments.

A comparison of the impact of clear-cutting and shelterwood cutting on flora in Norway spruce forests found that the latter was less destructive to the forest flora than the clear-cut system (Hannerz and Hånell 1997). The positive effects were most pronounced in vascular plants and bryophytes. That study was carried out in stands managed under the uniform shelterwood system; the authors indicated that using other shelterwoods (e.g. irregular shelterwood) may further reduce the impact of harvesting on the ground flora due to the retention of individual trees for longer periods of time.

Overall, O'Hara (2001) emphasises that the structure of individual stands is less important than the distribution of stands within a landscape from a biodiversity viewpoint. Biodiversity is likely to be maximised by landscapes that include both even-aged and uneven-aged stands (Kerr 1999).

It is generally assumed that uneven-aged management offers a more "scenic" alternative than even-aged management (Hoffman and Palmer 1996). There is some evidence to support this assumption. Ribe (1992), for example, explored the public perception of the scenic beauty of shelterwood and clear-cuts. He found that the clear-cut system was considered to have less scenic beauty than the shelterwood. Nielsen et al. (2007) and Meyerhoff et al. (2009) found that the public prefer more diverse stand structures and less intensive harvesting to single storey forests and clearfelling. More recently, a study investigating preferences for different forest types in terms of recreation revealed that the public in four regions of Europe, i.e. Great Britain, the Nordic Region, Central Europe and Iberia, preferred "close-to-nature" forestry over intensive even-aged forests and woody biomass production (Edwards et al. 2012). Forests that are older (50+ years) were preferred over any other phases of development, i.e. medium, young, and establishment. These results indicate that forests managed under CCF are likely to be preferred by the public for recreation as under these systems trees are retained longer until older and the forest structure is closer-to-nature.

<u>Economics of CCF management and the transformation to CCF</u>

A limited number of studies have addressed the financial implications of the transformation process. Davies and Kerr (2011) produced an economic analysis of the clearfell/replant system and the following three transformation scenarios for Sitka spruce in the UK (beginning at a stand age of 25 years):

1. transformation to a simple structure using natural regeneration (Scenario 1);
2. transformation to a simple structure using underplanting after the failure of natural regeneration (Scenario 2);
3. transformation to a complex structure (Scenario 3).

They compared the net present values (NPV) for each of the following CCF rotation scenarios, i.e. 20 years, 100 years and in perpetuity. Higher overhead costs of management were assigned to the transformation scenarios: 150% to the first two and 200% to the latter to reflect the lack of experience among UK forest managers in using these management approaches. The three transformation processes were found to be less costly than the clearfell and replant scenario over a 20-year period, a finding that was attributed to the high initial thinning returns during transformation (Davies and Kerr 2011). Over the 100 year period, the clearfell and replant produced the highest NPV, although the NPV for Scenario 1 was similar. Finally, the highest NPV value in perpetuity was recorded for Scenario 1 because natural regeneration is cheaper than artificial regeneration (even accounting for re-spacing costs). Davies and Kerr (2011) emphasise the importance of successfully achieving natural regeneration as the NPV of Scenario 2 which includes a requirement for underplanting was low for all options.

Knoke and Plusczyk (2001) also compared a transformation scenario with a clearfell system in Norway spruce in Germany. They found that the transformation strategy yielded lower levels of timber and income overall. However they noted that as the income from transformation occurred earlier and was more uniformly distributed over time, the NPV of transformation was greater than for the clearfell system.

A case study from Oregon, USA compared the short-term financial returns from different management options including a no-thin, thin for even-age, clearfell and a "partial cut for uneven-aged"; the latter was considered to mimic the early stages of a transformation process (Emmingham et al. 2002). The authors took a short-term view (10 years) as they considered this would be the time horizon over which most private forest owners in the US would make comparisons. The starting point was even-aged conifer and even-aged mixed conifer-hardwood stands, 40–60 years of age in Oregon. The authors calculated the net asset value and found that the transformation option was associated with little economic loss in the short term but that there were significant cash flow advantages to clear-cutting immediately.

Pukkala et al. (2010) investigated the optimisation of structure and management of Scots pine and Norway spruce forests in Finland. Based on NPV, they found that uneven-aged management was more profitable than even-aged management in all cases, except for Norway spruce stands on fertile sites when a low discount rate of 1% was applied. They concluded that decreasing site productivity and increasing discount rate improved the relative financial profitability of uneven-aged management. These findings coincided with those from a study from Spain (Sánchez-Orois et al. 2004) that focused on the optimal residual growing stock and cutting cycle in uneven-aged maritime pine stands. Uneven-aged management was shown to be more profitable on poorer sites with even-aged management being favoured on fertile sites according to the land expectation value (LEV). Wikström

(2000) concluded, in a case study from Sweden, that even-aged management was more profitable than the uneven-aged alternative due to higher volume increment and higher net present value (NPV). However, he does point out that the NPV of the uneven-aged option was 90% of the even-aged NPV.

In summary, a number of key factors influence the outcomes of financial comparisons of even-aged forests with uneven-aged forests. First, natural regeneration is a key element of transformation and successful natural regeneration results in substantial savings in restocking costs. Helliwell and Wilson (2012) attributed the adoption of CCF by an increasing number of private estates in the UK to the need to avoid the substantial costs of restocking of clearfelled areas. Where underplanting is required this cost advantage is negated. Second, thinning used in the transformation process to CCF will be heavier and commence earlier than in comparable even-aged clearfell/replant management. The resulting earlier and larger revenues skew the financial advantages in favour of the transformation process, especially when high discount rates are used (Knoke and Plusczyk 2001). Third, it is often assumed that larger and more valuable trees will be produced in CCF systems. Certainly retaining trees longer, which is a feature of the transformation process, will result in large trees. However, there are concerns as to whether sawmills will be able to process large logs and whether markets will exist for them. For example, Andreassen and Øyen (2002) suggested that processing of large sized-logs in most modern sawmills in Norway would be more expensive and would not attract a premium price. Such a price premium for large and higher quality timber would be necessary to cover the cost of growing trees longer (Moore et al. 2012). Therefore, market demand for large quality logs and a sawmilling industry set-up capable of handling such products is vital. A sufficiently large production of larger logs would have to be secured to justify the investments in the sawmilling industry. In addition, operation costs may be higher in countries with no such sawmilling set-up since experienced staff that are able to harvest large trees will be required (Ireland 2007). Larger logs are not necessarily more valuable logs. For example, MacDonald et al. (2010) noted that growing trees to older ages (which will be a feature of CCF management) may result in them having big branches, particularly in the upper part of the stem, which will have negative consequences for wood quality. In particular the development of final crop trees that are tapered for stability reasons will also encourage greater branch growth, longer retention of branches (i.e. deeper living crowns), thus resulting in larger knots. To counteract these effects, pruning on selected frame trees may have to be considered if economically justifiable (Henman 1963). In Germany 85% of uneven-aged forests are pruned (Hanewinkel 2001).

Knoke et al. (2001) considered the volatility of timber prices as a risk in terms of forest management, concluding that the *continuity of income* in CCF management was crucial. In addition, they highlighted that the clear-cutting system can be far more influenced by timber prices, in contrast to the process of transformation to CCF which offers a much better distribution of the harvest over time. Knoke (2012) further argues that CCF delivers small and frequent profits that out-compete the large but infrequent profits yielded by clearfell. Furthermore, once an uneven-aged structure is achieved, forest owners have more flexible harvesting options owing to greater log size diversity; this contrasts with even-aged stands where no income will be earned for a long time after clear-felling. However, Hart (1995) raises the issue as to whether timber prices would be negatively affected by the range of assortments that are typically produced in the one harvesting operation in an uneven-aged stand.

Economic considerations also play a role in determining when transformation of a stand should be initiated. Price and Price (2006) found in their study of a 37-year-old Sitka spruce stand in Wales that the transformation to CCF should ideally begin earlier in such stands at 27 years of age as they found this to be the financially optimal age for initiating the transformation process. Knoke (2012) highlighted that from an economic perspective it was disadvantageous to transform a stand that has exceeded financial maturity claiming it may be better to clearfell the stand at the end of the rotation and engage in the transformation process in the newly-regenerated stand.

Climate change and CCF

The growing interest in CCF has been attributed in part to the need for greater forest resilience to the effects of climate change (Diaci et al. 2011). This is due to a belief that forests managed under CCF are better able to adapt to the changing climate due to their diversified structure and stability as well as their wider genetic diversity (e.g. Stokes and Kerr 2009, Küchli 2013). Evans and Perschel (2009) recommend inter alia the use of uneven-aged silvicultural systems to increase forests' resilience and ability to adapt to changing precipitation and temperature patterns. Lafond et al. (2013) also recommend the use of uneven-aged silvicultural practices, specifically group selection with gaps of 500 m^2 as a means of promoting forest resilience for climate change adaptation. Carbon sequestration has also been shown to be influenced by the silvicultural system used. For example, Seidl et al. (2007) showed that a Norway spruce stand under CCF management accumulated more carbon than an even-aged equivalent. Stokes and Kerr (2009) highlight that there are many gaps in knowledge regarding the response of trees under even-aged stand management or CCF to a changing climate. Nevertheless they outline that in the case of Scottish forests, CCF has the potential to adapt forests to some of the risks associated with climate change. Yet they stress that in stands being transformed, the response to climate change will depend on the stage of transformation.

Examples of CCF transformation

The process of transformation has been pursued for over a century in some parts of central Europe; however, it has more recently developed in other parts of the world (Cameron et al. 2001). There are examples of long-term transformation experiments in Europe, e.g. the transformation of pure stands of Norway spruce and Scots pine in the Black Forest, in Germany (Kenk and Guehne 2001). In Glentress, in southern Scotland, a transformation trial has been on-going since 1952 (Kerr et al. 2010, Kerr and Mackintosh 2012). The original stand composition included European larch, Scots pine, Douglas-fir, Sitka spruce, Japanese larch (*Larix kaempferi* (Lamb.) Carr.) and Corsican pine (*Pinus nigra* spp. *laricio* (Poir.) Maire). The main method of transformation in this forest has been group felling followed by regeneration.

Another long-term trial based in Faskally Forest, in Scotland, has been undergoing transformation for 60 years (Cameron and Hands 2010). The forest was originally a mixture of Norway spruce, Scots pine, European larch, Douglas-fir, and European beech planted at the beginning of the 20th century. Transformation into an irregular structure initially involved planting small groups of native and introduced conifer and broadleaf species within the existing stand. The latter stages of transformation have involved the application of the selection system.

Conclusions and practical implications

Interest in the application of CCF has been increasing, primarily prompted by the change in society's views on how forests should be managed with the current paradigm being sustainable multi-purpose forest management where structural and biological diversity, amenity and recreation values are considered alongside timber production. Consequently the process of transforming even-aged stands to CCF has commenced in a number of countries. There has been little research on this process and there is limited information and guidance available to foresters who wish to avail of this option. This review revealed that the small amount of work that has been conducted to date on CCF has focussed on the initial stages of the transformation process. If transformation is to be successful it is important that forest managers should already have a vision of the "type" of forest structure they wish to develop using this approach. Further research and guidance will be needed to help them achieve this objective. A considerable proportion of the literature on CCF has emanated from the UK and Central Europe. While the UK literature has provided a valuable starting point for those engaged in transforming stands in Ireland, there is a need for further research to develop country-specific guidelines on the stages of transformation.

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The practice of continuous cover forestry in Ireland

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Abstract
There is increasing interest in continuous cover forestry (CCF) in Ireland, however little is known about the extent to which CCF is currently practiced. To this end, a survey of forest owners/managers was conducted in 2012 to determine the extent to which, and on what site types, CCF is being practiced in Irish forests. The survey revealed that there are 271 forests managed under CCF in Ireland, 235 public (Coillte and the National Parks and Wildlife Service) and 36 private, with a total area of 10,603 ha (8,292 ha and 2,311 ha, public and private respectively). The survey further indicated that the average size of a CCF forest property is 50 ha and that most of the forest area being managed under CCF comprises mixed-species stands. The survey further revealed that 66% of the properties have been managed under CCF for less than 15 years. A 10% random sample of the properties for which questionnaires were completed were visited. This showed that there was little evidence yet of management specifically directed at transforming stands to CCF – suggesting that CCF management was more likely to be an "aspiration" rather than a "reality" to date. Nevertheless it was shown that over two-thirds of the surveyed forest properties appeared suitable for CCF management. Although some initiatives have been taken to increase the awareness of CCF in Ireland, and to expose foresters to aspects of CCF management, more needs to be done if those aspirations are to be realised.

Keywords: *Silvicultural systems, transformation, thinning.*

Introduction

Forest cover in Ireland has increased from just 1% at the beginning of the 20th century to a current level of 10.8% (700,000 ha). This change in land use has come about as a result of an afforestation programme that began in the 1920s and expanded in the intervening years. The land afforested was, until recently, generally marginal or sub-marginal agricultural land typically in upland areas. On these exposed and relatively impoverished sites species choice was limited to conifers of mostly North American origin, e.g. Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and lodgepole pine (*Pinus contorta* Dougl.) (Upton et al. 2012). Subsequent management of these forests tended to be similar to that practiced in Great Britain where similar forest site conditions prevailed. This involved the use of the clear-cut silvicultural system followed by replanting. Stands were thinned on sites where windthrow was not a major threat (and where pulp markets were available) and

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artificial regeneration (planting) was used by necessity where afforestation took place. When restocking by natural regeneration became an option as forest stands reached seed bearing age, foresters did not exercise or consider this option favouring the "familiar and reliable" practice of replanting.

As was the trend in other countries, concerns began to be raised about the practice of clearfelling in Ireland in the 1990s (Ní Dhubháin 2003). The negative visual impact of this practice was one of the key issues raised during a public consultation process conducted by Coillte in 1998 (Pfeifer 1998). Alternative silvicultural systems to clearfell (or continuous cover forestry, hereafter CCF, as they were more commonly referred to) were gaining increasing attention internationally in the context of a wide societal debate on sustainable forest management and multi-purpose forestry (further details on the historical context to the current interest in CCF along with a review of the literature on transformation to CCF can be found in Vítková and Ní Dhubháin (2013; this issue)). Reflecting this, the forest area on which CCF is practised is used as an indicator of sustainable forest management in a number of national standards. The UK Forestry Standard, for example, requires managers to "identify areas which are, or will be, managed under a CCF system and to build them into the forest design" (Mason et al. 1999). The Woodlands for Wales Strategy (2001) included an aim to convert at least half of the National Assembly woodlands to CCF over the following 20 years, where practical, and to encourage conversion in similar private sector woodlands. In a recent review of this Strategy the target of 50% was removed, but the aim to use CCF remained (Welsh Assembly Government 2009). In the Irish National Forest Standard, the area of forest managed for CCF is included as a measure of sustainable forest management (Forest Service 2000). More recently two certification bodies, the PEFC and FSC refer to CCF in their Irish standards. The PEFC Irish Forest Certification Standard (2010, section 3.4.1.) indicates that "for woodland management units greater than 100 ha in size, 10% of this area will be identified and plans made for the phased implementation of low impact silvicultural systems with a preference for use of natural regeneration where parent seed is suitable" on windfirm sites with favourable soil conditions and suitable species. Less detail is given in the FSC Irish Forest Standard (2012) where indicator 10.3.2. merely states that "transformation to CCF shall be considered as a means of achieving management objectives". A new Forest Management Planning System was put in place in Coillte in 2005 wherein a silvicultural system was prescribed for each management unit within the estate. The process was revised in 2010 and at present there are 11,759 ha in Coillte with a CCF designation.

Previous research on CCF in Ireland

Research on CCF in Ireland has been limited. There has been research on natural regeneration, which is considered to be a key component of CCF. This research was prompted by the challenges for management arising from the sporadic occurrence of natural regeneration of Sitka spruce and lodgepole pine in Irish forests following clearfelling. For example, Von Ow et al. (1996) and subsequently Dagg (1998) explored the phenomenon of natural regeneration in Sitka spruce, identifying factors that influence its establishment. Tiernan (1998) studied natural regeneration in lodgepole pine, focusing on the distance from the seed trees that seed can travel. Further work on lodgepole pine regeneration was carried out by O'Keefe (2002), while O'Leary et al. (2001) quantified the extent of natural regeneration within the Coillte estate. The factors that influence the occurrence of natural regeneration of lodgepole pine and ash (*Fraxinus excelsior* L.) have also been identified (O'Leary 2000). The latter two studies were conducted as part of the first COFORD-funded project to examine CCF in Ireland "Alternative silvicultural systems to clearfelling" between the years 1999 and 2001 (Ní Dhubháin et al. 2001). The successor to that project, CONTINUCOVER (Ní Dhubháin 2010), explored how transformation to CCF might be initiated in both a mature and semi-mature Sitka spruce stand in Co. Wicklow. In the project, an underplanting experiment was established as well as a shade-house experiment. Specifically the key areas addressed in the research conducted as part of the CONTINUCOVER project were:

- the survival and associated growth rates of Sitka spruce, hybrid larch (*Larix x eurolepis* Henry), western red cedar (*Thuja plicata* Donn ex D. Don), European beech (*Fagus sylvatica* L.), downy birch (*Betula pubescens* Ehrh.) and sessile oak (*Quercus petraea* (Matt.) Liebl.) when planted under three different levels of canopy cover in a 40 year-old Sitka spruce stand (Coghlan 2007);
- the survival and growth of seedlings of the three aforementioned conifer species when grown in plots under shade-houses (Kennedy et al. 2006, Kennedy et al. 2007);
- the effects of scarification, fencing and seeding on regeneration of Sitka spruce within gaps created in a mature Sitka spruce stand (Ní Dhubháin et al. 2001);
- the relationship between light levels and stand characteristics in a Sitka spruce stand (Holzmann 2004).

Initiatives undertaken to date in Ireland in relation of CCF

The Association Futaie Irrégulière (AFI) is an international network of research stands established in 1990 by a working group, the aim of which is to study the development of the forest stand over time along with disseminating data on forest management practices (Süsse et al. 2011). A primary objective of the network is to demonstrate that the principles of CCF management can be used in a wide range of different situations. In 2007 a research stand was established by Coillte in Curraghchase Forest in Co. Limerick as the first stand in Ireland to become part of the network. In 2012 the network in Ireland was expanded to include a further six stands (Table 1). The AFI network records a detailed inventory of forest stands at five-year intervals and also records management inputs and outputs in the form of forest products. This allows for an economic analysis to be carried out in conjunction with the recorded inventories. The Irish AFI stands were selected as representative of a range of typical stands in Ireland which have the potential to be transformed to CCF. A key principle of the network is that joining the network does not change the management being undertaken in the stand (Poore 2006); it only requires the commitment to the inventory and record keeping as described above.

A number of Coillte foresters have been trained in marking trees for thinning as

Table 1: *A list of AFI research stands established in Ireland.*

Forest	County	Ownership	Year established
Monivea	Galway	Coillte	2012
Lackinrea	Waterford	Coillte	2012
Tikincor	Tipperary	Coillte	2012
Jenkinstown	Kilkenny	Coillte	2012
Knockrath	Wicklow	Private (D. Brabazon)	2012
Rahin	Kildare	Coillte	2012
Curraghchase	Limerick	Coillte	2007 (2012[a])

[a] re-measured

a part of CCF management. This training has been conducted in fixed area plots known as Marteloscopes in which a detailed inventory has been undertaken. The economical, silvicultural and ecological consequences of the marking decision made by the trainees are revealed to the trainees using software into which the inventory data have been inputted. The first Marteloscope training plot was established in Ireland in Curraghchase Forest in 2007, with a further three being set up in Ireland in 2013 (Table 2).

ProSilva Ireland, which was founded in 2000, is an organisation involved in promoting CCF on the island of Ireland. It is part of a wider network of similar organisations in 25 European countries under the umbrella of Pro Silva Europe. Its aim is to promote a greater awareness and understanding among foresters, forest owners, forest policy makers and forest industry members in general of CCF. Field visits throughout Ireland and study tours to Europe help members to experience CCF in practice and engage in networking with foresters, skilled in CCF techniques, who are actively using this approach to management. ProSilva Ireland also supports research into the dynamics of forest ecosystems and the adaptation and development of CCF (ProSilva Ireland 2013).

Coillte has adopted the principles of sustainable forest management, as laid down by the Forest Stewardship Council, and thus is committed to consider CCF in windfirm conifer plantations. Coillte adopted a Low Impact Silviculture Policy in 2005 and within that policy stated that all broadleaved high forests will be managed under CCF. In addition, CCF is the favoured option for management in amenity areas and old woodland sites within the Coillte estate. An increasing number of Irish

Table 2: *A list of forests stands where Marteloscope training plots were established (all sites are under Coillte management).*

Site	County	Main species	Year established
Curraghchase	Limerick	European beech (*Fagus sylvatica* L.)	2007
Tikincor	Tipperary	Sitka spruce	2013
Oughval	Laois	European beech, ash	2013
Donadea	Kildare	Pedunculate oak (*Quercus robur* L.), European beech, ash, mixed conifers	2013

private forest owners have also begun to consider, and commence the process of introducing, CCF in their forests. This is particularly the case amongst those private forest owners with a long experience in forestry across multiple rotations and generations. In general terms, economics appears to be the main motivation amongst this category of private forest owners who decide to transform to CCF. Many of these private forest owners also believe that CCF is more sustainable both ecologically and economically in the long term.

Despite the increasing interest in CCF in Ireland, to date no detailed information on the actual use of CCF in Ireland has been available. To address this information gap a study was initiated to determine the extent to which, and on what site types, CCF is being practiced in Irish forests. The results of this research are reported in this paper.

Materials and methods

To determine the extent to which CCF is practiced in Ireland, forest owners/managers were invited to complete a survey for each forest property in which they practiced CCF. Forest owners/managers in the following organisations were circulated: Coillte (which manages 57% of the forest estate (Forest Service 2007)), the Society of Irish Foresters, the Irish Timber Growers Association and ProSilva Ireland.

Information on the following was queried in the survey: forest name, location, county, nearest town, forest area and stand age, species composition (main and secondary species), duration under CCF management, presence of a forest management plan, presence of a designated area such as an NHA (National Heritage Area), SAC (Special Area of Conservation) or SPA (Special Protection Area), silvicultural system used, and additional comments relevant to the forest management.

A sample of the forest properties identified in the survey was randomly selected, visited and surveyed (10%, i.e. 27 sites) in spring 2013. The purpose of these property surveys was two-fold. Firstly, they were used to verify details submitted to the questionnaire. A second aim was to assess the suitability of the property for CCF management. This latter assessment was informed by Mason and Kerr's (2004) guide to site evaluation for transforming even-aged coniferous stands to CCF management. The properties visited were assessed according to the following attributes:

- stand stability (evidence of windthrow; crown development);
- presence of potential seed bearing trees;
- presence of quality stems (trees of good form; species suitable to the site);
- evidence of natural regeneration of any tree species (size and quantity; possible reasons for regeneration absence);
- extent of ground flora (presence of vegetation which might compete with any potential natural regeneration, presence of litter layer);
- evidence of browsing (browsing present on natural regeneration);
- need for deer management (culling or fencing);
- access and topography (state of within-stand infrastructure).

Results

According to the survey returns, CCF was being practiced in a total of 271 forest properties (36 private; 235 public) covering 10,603 ha (Table 3). The average size of these properties was 50 ha, but many were smaller than this (Figure 1a). Private properties where CCF was being practiced were larger, on average, than public properties with 25% greater than 80 ha. Co. Wicklow had the highest number of forest properties managed under CCF (Table 4).

Forest age

Almost 60% of all CCF properties were of mixed age (57% and 64% for public and private properties, respectively) (Figure 1b). There was a greater representation of older properties in the public sector.

The duration of CCF management

The duration of CCF management was relatively short with 66% of properties being managed using CCF for less than 15 years (Figure 2a). The average length of CCF management for public and private properties was 13.2 and 6.3 years, respectively.

Other characteristics of the forests surveyed

Sixty-four per cent of the area of the CCF properties comprised mixed species (i.e. more than one species) (Figure 2b). These mixed species forest properties consisted of mixtures of both broadleaved and conifer species (66%); the remainder comprised conifer mixtures (20%) and broadleaved mixtures (14%). Pure conifers formed a major part of the area of privately owned CCF properties, i.e. 62% versus 20% for public properties. Almost three-quarters of all the area managed under CCF

Table 3: *Information about Irish forest properties currently managed under CCF.*

	No. of sites	Forest area (ha)	Mean forest area (ha)	Mean length of CCF management (years)
Public	235	8,292	35	13.2
Private	36	2,311	64	6.3
Public & Private	271	10,603	50	9.0

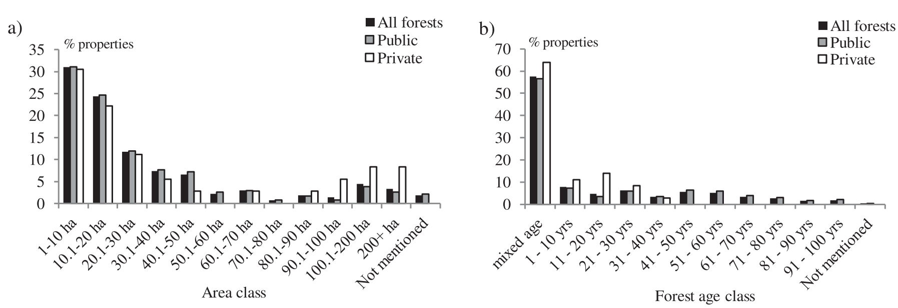

Figure 1: *a) the area managed under CCF; b) the age of the forest properties managed under CCF.*

Table 4: *Area and number of forest properties managed under CCF by county, and the number of these surveyed. County totals have been broken down into public and privately owned properties.*

County	Area (ha)			No. of properties			No. of properties surveyed		
	Total	Public	Private	Total	Public	Private	Total	Public	Private
Carlow	19	18	1	2	1	1	1	0	1
Wexford	24	0	24	2	0	2			
Clare	30	20	10	2	1	1			
Sligo	31	31	0	1	1	0			
Galway	76	76	0	3	3	0			
Mayo	81	82	0	3	3	0			
Kildare	103	103	0	2	2	0			
Longford	135	135	0	2	2	0			
Offaly	230	230	0	5	5	0	1	1	0
Leitrim	242	153	89	14	13	1	5	4	1
Kilkenny	245	199	46	7	6	1			
Cavan	254	254	0	4	4	0			
Roscommon	260	219	41	4	2	2			
Dublin	266	253	3	3	2	1			
Westmeath	350	350	0	2	2	0			
Kerry	351	351	0	7	7	0			
Limerick	362	362	0	3	3	0	1	1	0
Waterford	387	83	304	6	3	3			
Laois	464	228	236	12	9	3	2	1	1
Louth	562	562	0	2	2	0			
Cork	635	611	24	22	20	2	2	2	0
Monaghan	647	449	198	5	3	2	2	2	0
Tipperary	838	332	506	13	11	2			
Wicklow	4,011	3,191	819	145	130	15	13	13	0
Total	10,603	8,292	2,311	271	235	36	27	24	3

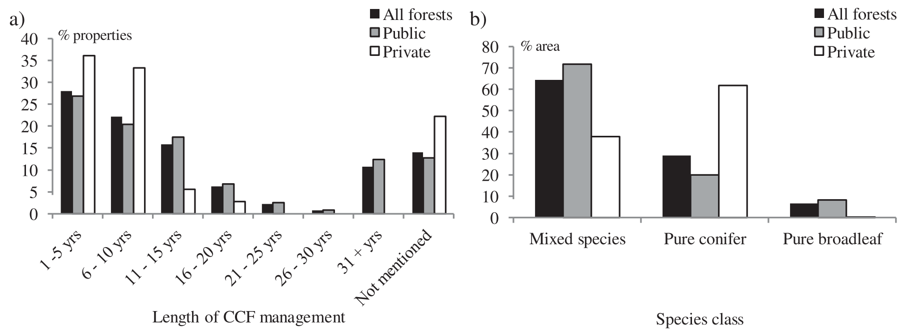

Figure 2: *a) the length of time the forest properties have been managed under CCF; b) the species composition of the CCF-managed properties.*

did not have an environmental designation (Figure 3a). Almost two-thirds of the CCF managed area had a management plan in place (Figure 3b).

Silvicultural systems used
For one quarter of the area managed under CCF, respondents did not specify the silvicultural system being used. Selection systems (group selection and single tree selection) were used to manage 49% of the total forest area; 62% and 2% in public and private properties, respectively (Figure 4). On a further 12% of the forest area, shelterwood systems (irregular shelterwood, group shelterwood and uniform shelterwood) were used; 8% and 23% on public and private properties, respectively.

Ground survey of selected forest properties
Ten per cent of the properties (i.e. 27 properties) for which surveys were returned were randomly selected for inspection. Two of these were found to be too young to be classed as "currently managed under CCF" (less than 12 years-old).

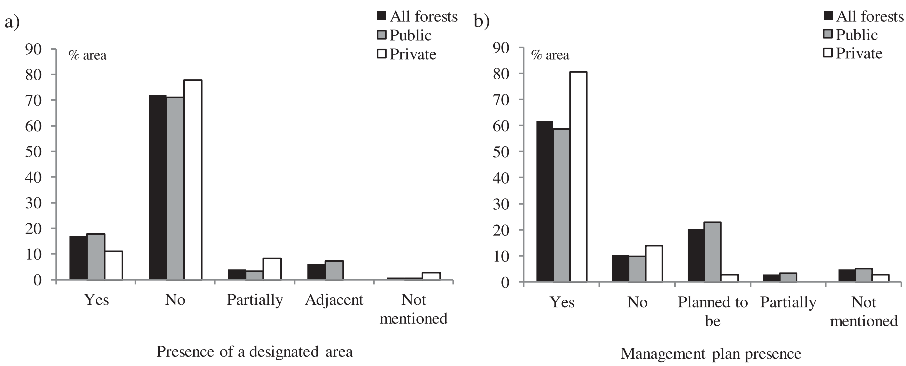

Figure 3: *a) the presence of a designated area in the CCF-managed properties; b) the presence of a management plan in the CCF-managed properties.*

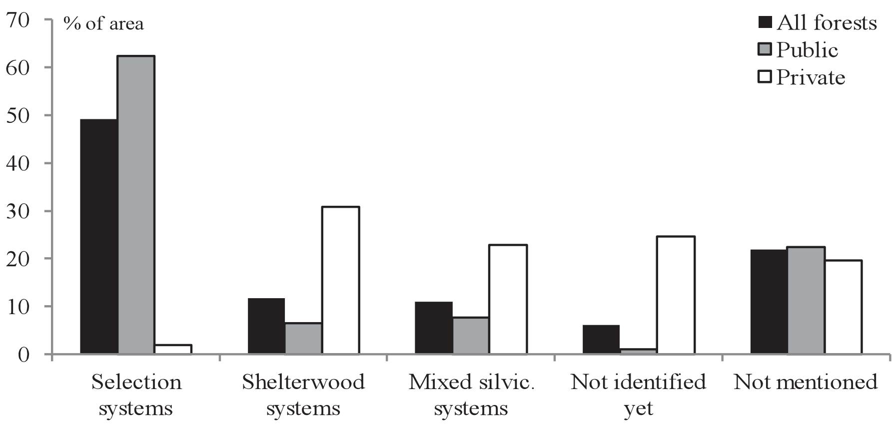

Figure 4: Silvicultural systems practised in properties managed for CCF.

Eighty-two per cent and 78% (Figure 5a, b) of the properties inspected were found to have good suitability and stability, respectively, with 80% having potential seed-bearing trees (Figure 5c). Almost half of the properties had trees with good stem quality (Figure 5d). Two-thirds of the properties had natural regeneration of all tree species present (Figure 5e). However, competing vegetation such as bramble (*Rubus* spp.), ivy (*Hedera* spp.), rhododendron (*Rhododendron* spp.), laurel (*Laurus* spp.), and various grasses were present on two-thirds of properties (Figure 5f). Evidence of deer browsing was found on 30% of inspected properties (Figure 5g) and was a particular constraint in Co. Wicklow where the majority of CCF sites were located (Table 4). The extent of browsing confirmed why 33% of properties were considered to need population management (Figure 5h). The infrastructure within half of the properties was found to be good. However, a further 33% required access roads to be constructed (Figure 5i).

The inspections revealed that only 11% of the properties did not exhibit any of the requirements for a successful transformation to CCF, while 7% had all the requirements (Table 5). Fifty-nine per cent had at least seven of the nine requirements. Although some additional deer management and vegetation control may have been necessary on some properties, in general, the majority of the sample of properties visited were found to be suitable for the application of CCF since they

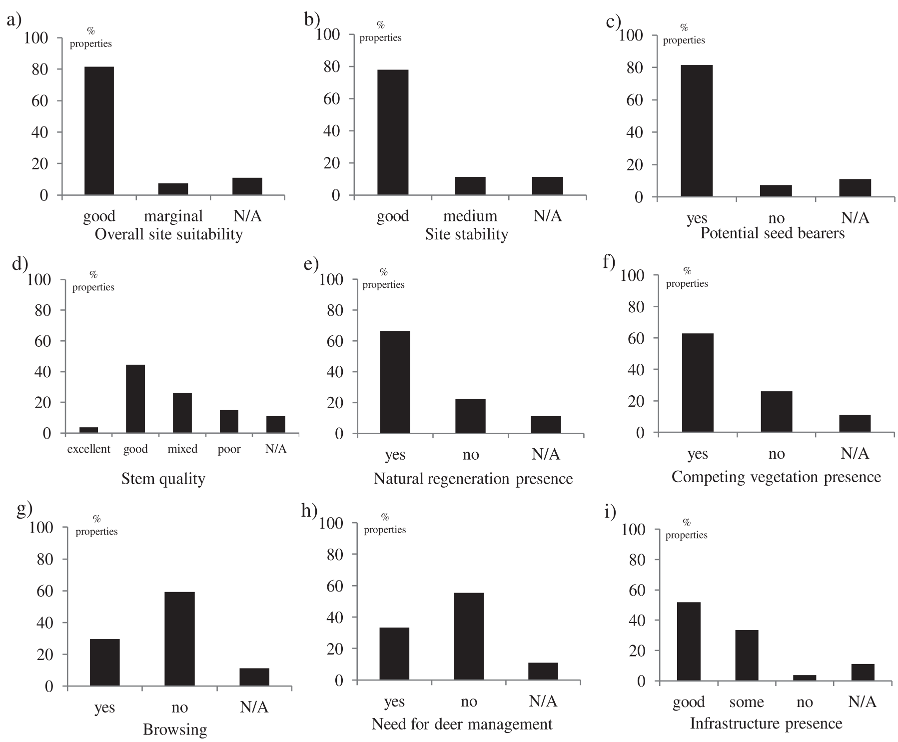

Figure 5: *Requirements for successful transformation to CCF based on a sample of properties inspected.*

Table 5: *Forest properties that fulfilled the requirements for successful transformation to CCF observed during the survey of forest properties.*

Number of requirements	% of sites fulfilling requirements
0	11
1	-
2	-
3	4
4	-
5	4
6	22
7	33
8	19
9	7

were regarded as stable with a presence of quality seed-bearing trees, with good overall stem quality and good within-stand infrastructure. Natural regeneration of tree species, which is a key element of CCF, was present on almost two-thirds of the properties indicating the potential of the trees on these properties to naturally regenerate.

Discussion

The increasing interest in CCF in Ireland is partly in response to the demands of society for alternative forest management approaches to clear-cutting. Within Coillte the process of certification and the subsequent engagement with the Low Impact Silviculture Policy are likely to have been the drivers for the expansion of CCF management in Coillte-owned forests. The reasons for engaging with CCF in the private sector may differ. These may include perceived amenity values and an overall interest and enthusiasm of the forest owners to engage with more "close to nature" forest management. Economic reasons may also be important as the threshold level at which forestry incomes become subject to income tax has fallen in recent years and is currently €85,000 per annum. Stands management under CCF can provide smaller but more frequent revenues below the tax threshold. In addition, some private forest owners also simply may not like seeing their forests being clearfelled.

Irrespective of what has promoted a desire for CCF management, forests managed under CCF are likely to have more complex structures in terms of sizes and/or ages of trees (Kerr 2012). CCF management will require an adaptive rather than a prescriptive forest management approach and forest management decisions will be driven by changes in the forest stand triggered by previous silvicultural interventions. Skilled managers are therefore required. Only a handful of foresters in Ireland, however, have experience of the practice of CCF and the process of transformation to this type of management (Ní Dhubháin 2010). The forests of Central Europe are commonly considered "templates" of CCF practice (Vítková and Ní Dhubháin 2013; this issue). However, CCF management under Irish conditions must differ and it is important that Irish foresters, along with colleagues in similar areas such as Wales, Scotland, parts of England and North West France, adapt suitable practices for local conditions.

A number of initiatives have been undertaken which should provide foresters with some exposure to, and experience of, CCF management. First, the expansion of the AFI network in Ireland will provide foresters with an opportunity to visit sites where transformation from even-aged forests to forests managed under CCF is being practiced and to gain an understanding of the consequences of silvicultural interventions over time. The AFI sites were chosen to represent the range of stands that could potentially be transformed to CCF under Irish conditions.

The implementation of CCF will require forest managers and owners to place a greater emphasis on the management of individual trees. Thinning will play a key role in the transformation process (Vítková and Ní Dhubháin 2013) and in the long-term management of CCF stands. Foresters should mark final crop trees ahead of thinnings, a practice that has not been applied routinely in Irish forests for some time, so new skills in this area may have to be developed. The Marteloscope training exercise is a tool that can facilitate the understanding of the consequences of stand interventions, including thinning, at the individual tree-level. In addition to this, new skills will be required by harvesting contractors (Ireland 2009).

Extent of CCF management in Ireland

The aim of the survey was to identify properties that are managed under CCF. Implicit in that aim was that the properties were being actively managed. Given the relatively short time period since Coillte has implemented its Low Impact Silvicultural Policy, it was anticipated that in a number of stands classed as being managed under CCF, the process of active management to deliver on that objective may not yet have commenced. Hence when the questionnaire was circulated, the accompanying email to Coillte stressed that stands should be under active management. The survey results indicated that 10,603 ha of forest are currently managed under some form of CCF in Ireland. However, the subsequent forest property inspections suggested that not all of these were under active CCF management. Active management is a key feature of CCF and Mason et al. (1999 p.2) stressed that CCF management "does not mean abandoning stand management or timber production". In the questionnaire a number of respondents had indicated thinning had taken place in the property. Although there was evidence of recent thinning at these sites, however, there were no signs of an active approach to the transformation process, i.e. no evidence of steps being taken to favour natural regeneration, to select and favour future frame trees, or to apply early thinning in young stands to gain stability. Furthermore, almost half of the forest area recorded by the survey was classed as being managed under "selection systems". This figure seemed rather high since the area managed under the selection system did not exceed 10% of the forest cover in countries such as Slovenia and Switzerland, where selection systems have been considered a traditional type of silviculture (Schütz et al. 2012). There may be a misunderstanding amongst some respondents with regards to the terms "selection systems" and "selective thinning" and perhaps the terms were being used interchangeably. The former denotes a specific silvicultural system (see Matthews, 1989), while the latter refers to a thinning pattern whereby trees are removed on the basis of their quality to fulfil the objectives of forest management.

In the case of Coillte forest properties, the Forest Management Planning System introduced in 2005 required a form of silvicultural prescription to be assigned to each Management Unit. There were two options: one being a variation on the clear-cut system, and the second option included CCF, long-term retention and small coupe felling which are considered Low Impact Silvicultural Systems by Coillte. The designation for CCF is too broad and does not provide sufficient detail on the silvicultural system needed to deliver CCF. As Yorke (1998) states, CCF is not a silvicultural system, but it involves "the use of silvicultural systems whereby the forest canopy is maintained". A more precise indication of which silvicultural systems can be employed is needed to enable forest managers to identify suitable systems for a given site and actively engage with the transformation process to CCF management. As Mason and Kerr (2004) stated, a management plan outlining the objectives and proposed silvicultural system(s) with aspirations for a desired forest structure is a perquisite to ensure successful CCF management.

Species composition and CCF practice in Ireland

Conifers make up approximately three quarters of the forest estate in Ireland (Forest Service 2007). However, only 28% of the area of CCF-managed forests recorded in the survey (both public and private) was made up of conifers. In the private sector, the survey revealed that conifers form 62% of the CCF-managed forest area. However, the majority (64%) of the forest area reported on was of mixed species composition, including broadleaves and broadleaf/conifer mixtures. The large proportion of broadleaf forests under CCF management in Coillte is undoubtedly a reflection of the company's decision in 2005 to assign all its broadleaved forests to CCF management including those comprising pure stands of broadleaves, mixed broadleaves and broadleaf/conifer mixtures where the broadleaves were the primary species. This was an important shift in the management of public forests in Ireland. However, such a shift may also have triggered a belief that CCF tends to be primarily suited to broadleaved forests. Experience from Europe shows that CCF is practiced in a wide range of forest types, including those with a substantial coniferous component (e.g. Glöde and Sisktröm 2001, Kenk and Guehne 2001). Coniferous species also form a key component of the species mix in CCF transformation trials in the UK (e.g. Cameron and Hands 2010, Kerr et al. 2010) and, as shown in this study, in private sector forests in Ireland.

Suitability of Irish forests for CCF

The site inspections identified that the vast majority of CCF designated sites had at least six of the nine characteristics identified by Mason and Kerr (2004) as pre-requisites for stands being transformed to CCF. Forest stability is an important aspect of the transformation to CCF and its subsequent management (for details see Vítková and Ní Dhubháin 2013, this issue). The inspections showed that 78% of forest properties appeared to be stable with no obvious presence of windthrow (Figure 5a). Sufficient natural regeneration is generally considered a key pre-condition to successful transformation once stand stability has been achieved (Schütz 2001). It is however, important to note that the process of transformation often begins before the initiation of seed production (see Vítková and Ní Dhubháin 2013), so it may not always be possible to determine this when assessing the suitability of a stand for CCF. Nevertheless, the site inspections showed that although there was evidence of vegetation competing with natural regeneration and browsing by deer on 63% and 30% of the properties inspected respectively, natural regeneration was present on almost three-quarters of the properties inspected (Figure 5). CCF management emphasises log quality; although 15% of the inspected properties did not have trees of good quality, 44% and 4% of properties had stems of good and excellent stem quality, respectively. In 82% of the inspected properties there were potential seed-bearing trees denoting the potential for natural regeneration of trees of good quality.

Consequences of CCF management for the sawmilling industry

One of the primary objectives or economic drivers of CCF is to "provide a regular income over time by producing a high proportion of high quality large wood or very large wood" (Süsse et al. 2011 p. 25). If CCF is practiced on a greater scale that it has been to date, a greater quantity of larger logs from a range of species would be available. Currently, the sawmilling industry here is not set up to cater for processing large dimension logs >60 cm, which is the standard diameter of spruce logs processed in CCF forests across much of Europe. This is a part of a "vicious circle", where there will be an increased supply of larger logs, while on the other hand, the market for larger logs has not developed enough to cater for such dimensions. Upgrading some sawmills to handle larger logs may be costly, but the growing demand for CCF may present opportunities for investment by the sawmilling industry if the supply of larger logs produced as a result of CCF management materialises.

What is needed to improve knowledge of CCF in Ireland?

More detailed CCF methodologies specific to Irish conifer plantations are needed. Although some research on the practice of CCF in Ireland has been carried out (see introduction for details), these studies have mainly focused on aspects of natural regeneration. As part of the study outlined in this paper, an experiment on thinning patterns that could be used in the transformation process has recently been set up. However, further research and training is required if CCF is to be adopted on a larger scale.

Limitations to the survey

It was hoped that the survey would encompass a significant proportion of the stands being managed under CCF in Ireland. In the case of Coillte, the survey returns represented approximately 70% of the area classed as being managed under CCF by the company. It is believed that the request to complete the survey for forests "actively" managed may account for this shortfall and would suggest that the data returned in the survey represents a more accurate picture of the extent of CCF management. Since completing the survey, however, there has been a renewed emphasis on the management of the broadleaf estate within Coillte. A thinning prescription has been put in place for Coillte-owned broadleaf areas and it was envisaged by Coillte that the area managed under CCF will be larger at the next Forest Management Plan review. The survey is unlikely to have gauged exactly the level of CCF management in the private sector. However, those with extensive experience of working with CCF stands in the private sector have indicated to the authors that the majority of the area under CCF management in the private sector was included in the survey, so the results were likely to have been representative.

Conclusions

This study presents a snapshot in time of the status of CCF in Ireland. There appears to be no single overwhelming economic, ecological or policy driver that causes forest owners to decide to adopt this approach to forest management. Neither is there any overwhelming pattern to the type of woodland being transformed. It is clear that Irish forests being transformed to the silvicultural systems that deliver CCF are still at the beginning of this process and there is no clear pattern as to what system will be best adapted to Irish conditions. In this regard, there is more aspiration than certainty in how these forests will be managed in the long term. Nevertheless, there are clearly significant areas being nominated as CCF and a repeat survey in five or ten years will give an indication of the rate of this change and the success or otherwise in transforming even-aged plantations to more structurally diverse forests.

Acknowledgements

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The potential for using a free-growth system in the rehabilitation of poorly performing pole-stage broadleaf stands

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Abstract

This paper is a literature review of the free-growth system, which may have potential for the rehabilitation of some poorly-performing pole-stage broadleaf stands. It involves releasing of a selected number of good quality stems from crown competition as a basis for the final crop. Generally, only stems with crowns adjacent to the potential final crop trees are removed. The aim is to increase diameter growth of the selected stems and thereby shorten the rotation length needed to achieve a given diameter. The treatment may result in a greater incidence of epicormic shoots, particularly in oak (*Quercus* spp.). To maintain stem quality, epicormics may need to be removed, which may make the free-growth system uneconomic. There is, however, some evidence to believe that this may not be the case. In addition, the free-growth system may also be applicable in species less prone to epicormics, such as ash (*Fraxinus excelsior* L.) and sycamore (*Acer pseudoplatanus* L.). The free-growth system may prove to be a useful system for the rehabilitation of poorly performing pole-stage broadleaf stands and, with the advent of Chalara ash dieback (caused by *Hymenoscyphus pseudoalbidus* V. Queloz et al.) in Ireland, may gain greater use for its ability to reduce rotation lengths.

Keywords: *Broadleaf silviculture, management, rehabilitation, free-growth, crown release.*

Introduction

As part of a Teagasc 5-year COFORD-funded research programme on the silviculture of broadleaf plantations (the B-SilvRD project), being conducted in cooperation with University College Dublin (UCD), silvicultural systems suitable for the rehabilitation of poorly performing pole-stage (10 to 20-year-old) stands are being investigated. Hawe and Short (2012) reviewed possible causes of poor performance in broadleaf stands and referred to systems that may have potential to bring some poorly performing pole-stage stands into production. Short and Hawe (2012) reviewed one such system: coppice-with-standards. This paper considers another system – a modified free-growth system – and its potential for converting poorly performing pole-stage broadleaf stands into productive crops. The free-growth system has been suggested as a possibly suitable silvicultural system by a number of authors (Hawe and Short 2012, Evans 1984, Kerr and Evans 1993) for stands that are marginally poor; that is, stands which have sufficient relatively good quality and relatively vigorous stems to make up a final crop (Figure 1).

In some broadleaf stands that are performing poorly due to malformed stems, a free-growth (or similar) system may be applicable to bring the stand into more

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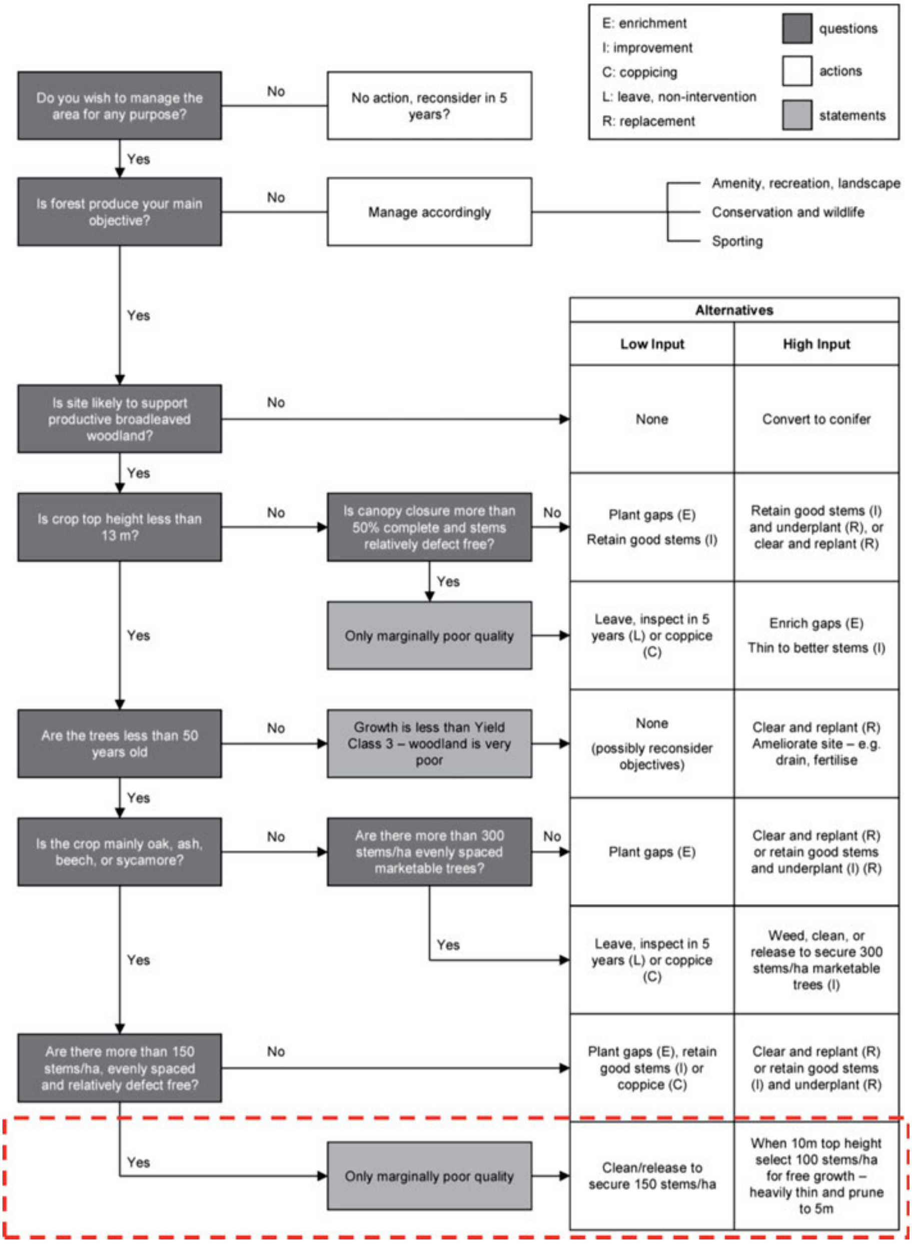

Figure 1: *Silvicultural options for managing neglected woodland. Redrawn from Evans (1984) and Kerr and Evans (1993).*

profitable production and to shorten the rotation to enable replacement with a more productive species and/or system. This paper reviews the free-growth system, focussing predominantly on broadleaf species. It includes comparisons of stem radial growth under conventional thinning systems and also describes a site that is being used as a pilot trial.

Free-growth is "a system which stimulates vigorous crown development of selected trees, in order to achieve maximum radial stem increment" (Jobling and Pearce 1977). It has also been called "free-thinning" and is associated with "crown release" thinning. It has been described previously (see Anon., 1955) as a heavy crown thinning in which "a limited number of the best dominants, usually about 100 per acre (250 ha^{-1}), are freed from all crown competition from the first thinning onward by cutting out any tree that touches the crown of a selected tree." Free-growth could be viewed as an intense form of selective crown thinning. In conventional thinning, competition is reduced within the remaining crop, either systematically or selectively, which facilitates the continued growth of the remaining stems. The intensity of thinning is correlated with the proportion of competition removed; high intensity thinning removes the majority of crown competition. A free-growth system includes thinning to the point that there is virtually no stem competing with a selected stem at any time after first thinning.

Conventional thinning and free-growth

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

- To reduce stand density and hence to reduce competition, leaving 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 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, or for amenity, recreational, or ecological reasons.

A given thinning intensity can be achieved in different ways with respect to the size and crown of trees that are removed. A useful indicator of the size of tree removed, and for describing the thinning type, is the ratio of the mean volume per stem of thinnings removed (v) to the mean volume per stem of the stand *before* thinning (V). The type of thinning can be classified as in Table 1 (Savill et al. 1997). It follows that free-growth thinning will have a v/V ratio in the region of 1–1.2, depending on whether lower canopy trees are also cut or left within the stand.

Selecting crop trees

Among many variations of selective thinning methods is the early selection of final

Table 1: *The variation of the v/V ratio (ratio of the mean volume per stem of thinnings removed to the stand mean volume per stem prior to thinning) with thinning approach used.*

Thinning method		***v/V* ratio**
Systematic methods	Line and strip thinnings	1.0
Selective methods	Low thinning	≈ 0.6
	Intermediate thinning	≈ 0.8
	Crown, or high thinning	≈ 1.2
Combinations of systematic and selective	e.g. Queensland selection thinning (Forestry Department, Brisbane, 1963)	Variable

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, at the outset it is necessary to mark two or three times the number that will actually form the final crop (Savill and Evans 2004). Garfitt (1995) describes a compromise employed in some Belgian forests that fulfils this objective where the crowns of 200 selected stems ha^{-1} are freed from immediate competition and the remainder are ignored. A suitable baseline is selected, for example a straight ride forming a boundary of the compartment. A stem is selected arbitrarily about five paces inside the crop at right-angles to this line, and is painted with a white band at eye-level, the "marker". The two best stems are then selected within a radius of five paces of this marker, and banded with yellow paint. They must be far enough apart to allow each to develop at least to pole-size without mutual interference. Each yellow-banded tree is then freed from immediate competition by felling surrounding stems to give 1.5 m clearance all-round the crown. The forester then walks ten paces from the marker, parallel to the base-line, and the nearest stem to this point is marked with a white band, as a second marker. Markers may be of any species and any shape; their function is simply to permit an even distribution of potential crop trees. The same procedure is then used again and the process continues, sighting back along the markers to ensure that the line is straight, until the boundary is reached. Then a right angle offset is taken and the process is repeated once more, parallel to and 10 m from the previous line. In this way two good stems are selected and given room to grow for every 10 m^2, thus providing two candidates from which to select the final-crop tree at a later date (Garfitt 1995). This process results in 200 candidate stems per hectare being selected and can be carried out in either a plantation or a stand resulting from natural regeneration. Short and Radford (2008) have outlined another approach – the "2-stick method" – that results in a specified density of trees being selected. Applying the Short and Radford method results in stocking between 350 and 500 stems ha^{-1}, but the method can be modified to result in any required number of selected trees, as long as the trees were planted in lines. It is not suitable for stands derived from natural regeneration.

Free-growth in conifers

Gehrhardt (1925), in his "rapid growth treatment" of spruce (*Picea* Mill. spp.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and beech (*Fagus sylvatica* L.), wanted to achieve a rapid increase in the diameter of the individual stems by early heavy thinning interventions. The crowns of selected trees should not be allowed suffer but be assured of the crown-space necessary for them to grow free of competition. The stand matrix should disappear as quickly as possible as being superfluous or as troublesome competition. The crowns of the selected trees should remain free of competition through to the end of the rotation by continuous thinning and the lower portion of their stems should be pruned (Gehrhardt 1925; cited in Köstler 1956, p. 248). Gehrhardt envisaged that by following these procedures it would be possible to demonstrate: (i) a rise in volume production and (ii) a shortening of the rotation. However, it did not gain support because examples of the rapid growth treatment were not very attractive and yield projections were questioned. Köstler (Ibid.) was of the view that the lack of timber may in future perhaps compel the adoption of similar measures in pure stands of spruce and beech. The size of the stems produced by Gehrhardt's system is shown in Figure 2 in comparison to a moderate thinning system. It is clear that "rapid growth treatment" produces a larger stem and will reduce the time to felling at a target diameter.

The "Scottish Eclectic" thinning method (Macdonald 1961) went further than Gehrhardt's system. The eclectic method recommended the selection and pruning of approx. 150 stems ha^{-1} and to release them from seriously competing dominants. Additional smaller good quality trees (followers) were also selected and released from competition. Finally the better quality stems from within the matrix as yet unthinned are released from competition and pruned. This method was used in Northern Ireland from 1961 in Norway spruce (*Picea abies* (L.) H.Karst.), Sitka spruce (*P. sitchensis* (Bong.) Carr.) and Douglas fir which had already received one light low thinning and was likely to produce sawn timber (Fitzpatrick 1966, p. 105).

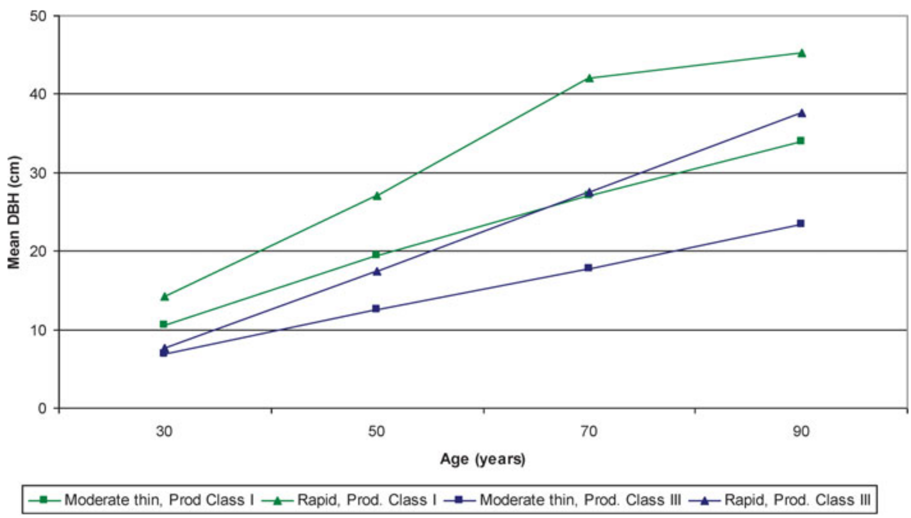

Figure 2: *Mean diameter at breast height (DBH) of Gehrhardt's "rapid growth treatment" in spruce stands of two productivity classes. Adapted from Köstler (1956); Table 60, p. 249.*

It commenced when the plantation was 7.5–9.0 m tall. Some 100–125 final crop trees ha^{-1} were selected and pruned progressively to 7.5 m height. The dominants were then isolated in a heavy thinning by removing competing dominants and sub-dominants, providing room for rapid growth. Smaller trees were retained as ground cover. Fitzpatrick does not explain whether additional, smaller, stems were identified, pruned, and released from competition as per Macdonald's (1961) description of the system.

Free-growth in broadleaves

It was not until 1950 that research on free growth of broadleaves began in Britain, but little research of this kind has been undertaken in Ireland. The first study examined several hundred hedgerow and parkland oak (*Quercus* spp.) and showed that these free-grown trees had substantially greater radial increment than trees in forest stands (Hummel 1951). This led to the suggestion that selecting a relatively small number of well-formed trees early in the rotation and encouraging a clean bole by pruning could result in a complete stocking of valuable trees at maturity.

Kerr (1996) reported the findings of an experiment that included the free-growth of oak (*Quercus petraea* L. and *Q. robur* L.). After a free-growth treatment was applied to a 19-year-old plantation, DBH and stem volume increased compared with the control and light crown thinning treatments. However, pruning of epicormics was required to ensure stem quality was maintained. This led Kerr to the conclusion that this may have been the reason that free-growth of oak has not been widely used in Britain and that it may be a silvicultural system more applicable to ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.), cherry (*Prunus avium* L.) and mixed stands of these species.

Free-growth primarily releases selected crop trees and

- favours only the crop trees, leaving the remainder of the stand unthinned;
- favours desired trees using a combination of thinning criteria;
- releases crop trees without strict regard to the position of the trees in the crown.

In an experiment outlined in Jobling and Pearce (1977), a free-growth treatment of oak consisted of 74 dominant trees ha^{-1} of equal dimensions in a 19-year-old plantation being selected, while preserving a space equal to approximately one half of the crown width around them at all times. The thinning cycle was three years. When the trees were 33 years-old, the free-growth treatment was thought unnecessarily severe and the prescription of space allowed around the crowns was altered from one half to one quarter of the crown width (Jobling and Pearce 1977). A comparison of the DBH of oak grown in a free-growth system with that in a conventional intermediate thinning system is shown in Figure 3. Note that, at 100 years of age, the selected free-growth oak have an annual diameter increment of 6.7 mm yr^{-1}, compared with approximately 4.5 mm yr^{-1} for the remaining stems. There is a slight discrepancy with the annual increments given by Evans (1982) for Yield Class 6 oak as averaging 8–9 mm yr^{-1} under free growth compared with about 5 mm yr^{-1} for conventionally thinned dominants, but the trend is similar.

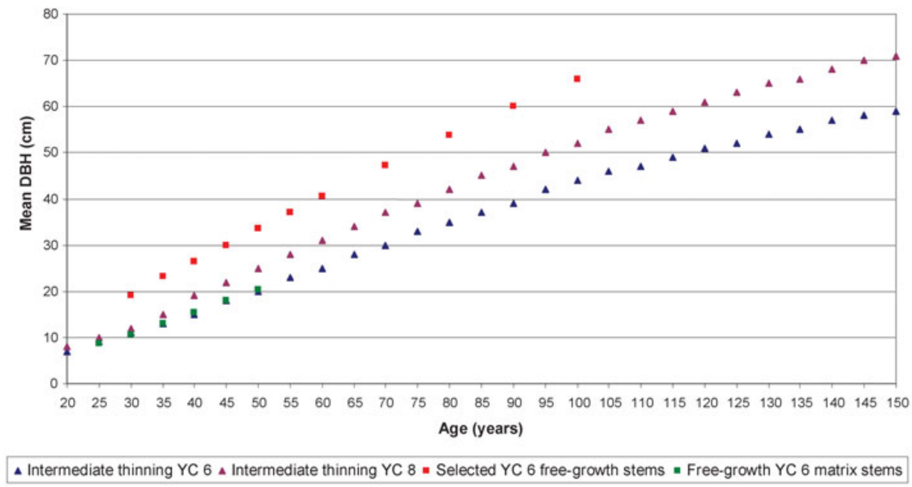

Figure 3: *Mean diameter at breast height (DBH) of maincrop oak. Data from Jobling and Pearce (1977; p. 9) and Edwards and Christie (1981).*

A similar trend of increased DBH in free-grown stems compared to conventional thinning can be seen for cherry (Figure 4). Similar to the previous example, the stems grown in free-growth systems show higher DBH increment, which if maintained, will result in a shorter rotation to a specified target diameter. Cherry is particularly intolerant of lateral crown competition. If a tree's crown growth is restricted, then the stem DBH increment will also be restricted. Even dominant stems can suffer crown dieback if their growth is severely restricted (Pryor 1985). Therefore thinning should be sufficiently heavy and regular to ensure that the crowns of selected trees remain unimpeded until the next thinning. The aim of the free-growth system is to facilitate this objective and may be useful for other similar species, such as ash.

The free-growth oak yield tables of Jobling and Pearce (1977) have been used to compare the financial performance of free-growth oak with traditionally managed oak. Beinhofer (2010) modelled the free-growth system, with and without pruning, and compared it with conventional management. Results from the model showed that oak that is grown under the free-growth system and is pruned, provides a better financial return than conventionally grown oak or unpruned free-growth oak. The free-growth oak approach was still more financially attractive even if the stand was not pruned.

As has been highlighted by Kerr (1996), the free-growth system can be labour intensive in oak due to the pruning and control of epicormic shoots. While this may be true, Beinhofer's economic model suggests that it is still more economic to grow oak under the free-growth system than in a conventional system, whether pruning is carried out or not.

Jobling and Pearce (1977) recommended the following silvicultural operations

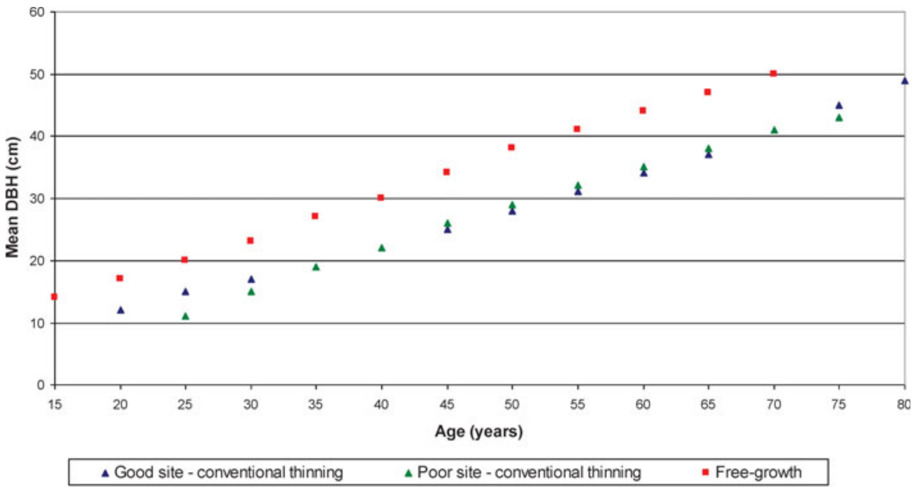

Figure 4: *Mean diameter at breast height (DBH) of cherry (Prunus avium L.) main crop under free-growth or conventional thinning systems. Data from Pryor (1988; p. 18–19).*

for the free growth of oak with the objective to produce veneer quality timber on a rotation of less than 100 years:

1. when mean height is >8 m select 60–80 well-formed dominant trees ha^{-1} evenly spread through the stand;
2. remove all trees whose crowns are within one quarter of the mean crown width of the crown of the chosen trees by thinning;
3. rigorously control epicormics and high prune to remove side branches, ultimately to a height of 6 m;
4. repeat thinning around selected trees every 3–5 years to maintain crown freedom.

There are few references to thinning regimes similar to free-growth in continental Europe. Lemaire (2010; p. 73) described a thinning regime for oak in France (Silviculture Dynamique) in which 70 stems ha^{-1} are selected as the final crop trees before the dominant tree height is 16 m. The selected stems must be free from disease, dominant in the canopy, of good stem form and spaced 6–18 m apart. All stems that are competing with the canopy of the selected stems and <2 m from the canopy of the selected stems are thinned. This regime leaves stems that are within the 2 m but are suppressed or not competing in the canopy. The selected stems are also high pruned as required. The whole procedure is then repeated again 6 years later. The objective of this "silviculture dynamique" system is to produce high quality oak in a rotation of less than 100 years. A target diameter of 65 cm can be attained within 80 years on highly fertile sites using this system. Hein and Spiecker (2009) modelled the growth of ash and sycamore with the objective of producing a target diameter within shorter rotations. Their model suggested that a target diameter of 60 cm could be attained within 60 years by ash and sycamore if the number of crop trees was 61 stems ha^{-1} and 69 stems ha^{-1} respectively. This would require that the mean canopy size is large and therefore would require heavy crown thinning or free-growth.

The expected crown diameter of ash for any mean stem diameter can be calculated as per Hemery et al. 2005. It therefore follows that mean DBH (cm) can be derived from crown diameter (m):

$$\text{DBH} = (\text{Crown diameter} - 0.75810) / 0.203565 \quad (1)$$

As crown diameter gets larger, stem diameter also increases. This is especially applicable to ash because it does not respond well to delayed thinning; all thinnings should be heavy with the aim of keeping crowns entirely free of competition. The crop should be at its final spacing by age 30 to 35 (Savill 1991).

There are a number of published studies from the US which have relevance. Erdmann et al. (1985) described the results of a number of thinning treatments on 54-year-old red maple (*Acer rubrum* L.) in Michigan. Some of the treatments were free-growth treatments (called crown release treatments). The crown-thinning treatments were applied to groups of six well-matched trees within each of three crown classes: dominant, co-dominant and intermediate. Six treatments were examined: 1) unreleased control; 2) single-tree release; 3) two-tree release; 4) 1.5 m release; 5) 3 m release, and 6) 4.6 m release. Only the most important crown competitors were cut in the single-tree and two-tree treatments. All surrounding trees, including intermediate and suppressed trees, whose crowns were within the specified distance of the study tree's crown perimeter were cut in the 1.5, 3, and 4.6 m crown-release treatments. These three treatments are forms of free-growth treatment. No thinning occurred in the matrix beyond the treatment areas. After seven years the diameter of crown-released trees had grown 90% faster than the controls, and 33% faster than when only one or two crown competitors were removed. The 1.5, 3.0, and 4.6 m crown release treatments were equally effective in stimulating diameter growth over the 7-year period (Figure 5), implying that canopy closure and resultant crown competition had not occurred within this timeframe.

The 5- and 10-year effects on growth of a free-growth thinning in four hardwood species in Maryland and West Virginia, USA, was reported by Miller (2000). The experiment was carried out in stands that were 12–16 years-old at the time of treatment. Black cherry (*Prunus serotina* Ehrh.), yellow poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.) and chestnut oak (*Quercus prunus* L.) crop trees were selected and, in the release treatment, all competing trees with canopy touching the crown of a selected crop tree were removed. At one site an additional, higher intensity release treatment was carried out in black cherry and yellow poplar only. All competing trees within 5 ft (1.5 m) of the crown of the selected crop trees were removed in this "release +5" treatment. In both the release treatments there were cases where adjacent crop trees were left touching each other and the treatments were applied around both crop tree crowns. The crown release treatments significantly enhanced the DBH (see Figure 6) and crown growth of the four species, with no adverse effect on survival or crown position for 10 years after treatment. However, too much growing space can be detrimental to height growth of

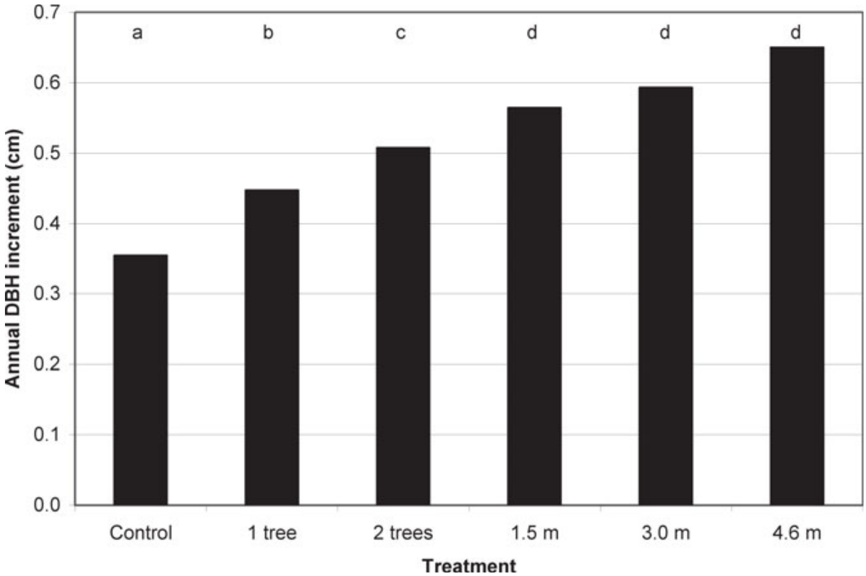

Figure 5: *Annual diameter at breast height (DBH) increment 7 years after crown thinning treatments in 54-year-old dominant red maple in Michigan. See text for treatment descriptions. Treatments with different letters are significantly different p ≤0.05. Source: Erdmann et al. 1985.*

black cherry and yellow poplar, as indicated by results of the release +5 treatment. Miller (2000) concluded that the release +5 treatment should not be prescribed because it could potentially lead to reduced height growth and possible crown class regression. The release +5 treatment was also found to reduce stem quality. It reduced clear stem development by an average of 10 ft (3 m) and the canopy was still open 10 years after treatment. The release treatment reduced clear stem development by an average of 4 ft (1.2 m) for black cherry and yellow poplar and the canopy was nearly closed 10 years after treatment, facilitating natural pruning. Miller's (2000) results suggest that a crown-touching release is an effective, low-risk cultural treatment for young hardwood stands and this treatment is being recommended for young hardwoods in the US (Miller et al., 2007).

Crop-tree release was found by Ward (1995) to increase 4-year stem diameter growth of northern red oak by 86%, black/scarlet oak (*Quercus velutina* Lamb., *Q. coccinea* Muenchh.) by 65%, red maple by 56%, and black birch (*Betula lenta* L.) by 52% in Connecticut compared to unreleased trees. Height growth of the upper canopy oaks was suppressed with increasing crown release during the first two-year period after the treatment but stabilised during the second two year period.

Ash dieback caused by *Hymenoscyphus pseudoalbidus* V. Queloz et al. (commonly called Chalara because it was first described as *Chalara fraxinea* T, Kowalski in 2006) has become more prevalent in Europe during the last decade, so silvicultural strategies have recently been published for the management of affected stands (Thomsen and Skovsgaard, 2012). The strategy recommended is dependent

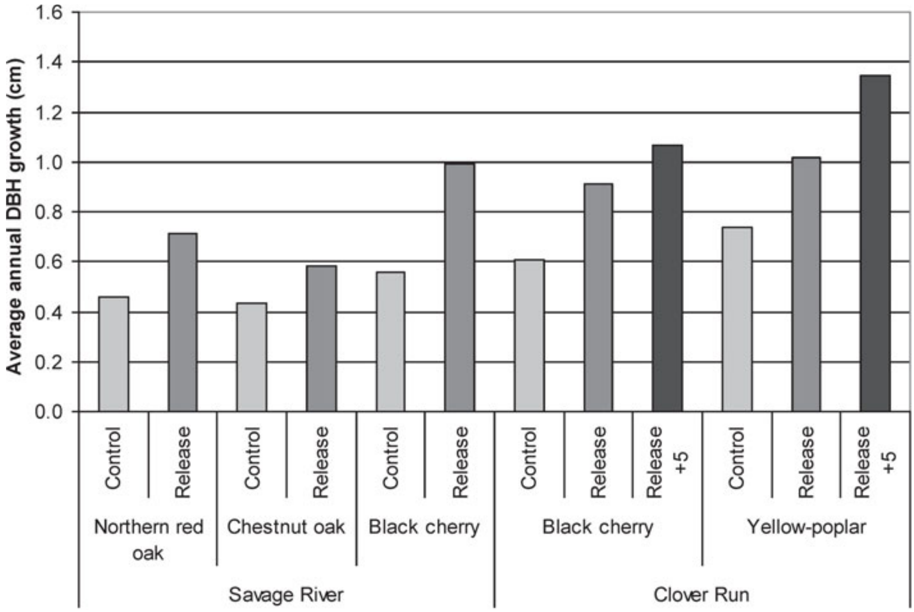

Figure 6: *Average annual diameter at breast height (DBH) growth 10 years after release treatments of four North American 10–16 year-old hardwoods (Miller 2000).*

on the age of the stand and the intensity of infection; severely infected young stands should either be clearcut and replanted, or surviving ash trees should be used as shelter and replanting carried out beneath their canopy. Young stands that have a high percentage of healthy trees should either be retained or more than 200 stems ha^{-1} should be marked and a thinning carried out among the unmarked trees. Older stands should be inspected and all trees with epicormic shoots should be felled as soon as possible to prevent stem wood discolouration through infection of such shoots. Where most of the primary crown is dead and survival is based on epicormic shoots in the crown, the tree should be harvested within the following year. Where >50% of the primary crown is dead the tree should be considered for harvesting. A tree may be considered healthy enough to keep for several years if >75% of the primary crown is intact, unless there are signs of honey fungus (*Armillaria* spp.) fructifications at the base of the tree. It appears that this two-pronged approach has two different objectives. The objective for the younger stands is to maintain productivity and health of the remaining stand, while the objective for the older stands is to harvest merchantable wood prior to any detrimental impact on quality caused by dieback. The free-growth system may have applicability to ash dieback affected stands. Similar to that recommended by Thomsen and Skovsgard (2012), 150 potential crop trees ha^{-1} could be selected and then a free-growth thinning carried out which, in addition, should also remove dieback-affected trees from within the matrix. However, this may open the canopy to such as extent that, on some sites, the stand could be at risk of wind damage.

Pilot trial work

A modified free-growth system is being investigated by the B-SilvRD project as a pilot trial in a privately-owned ash stand in Co. Mayo, planted in 1992. The site is 50 m above sea level. A single 20 × 20 m plot was established in the winter of 2010/11. A similar management approach has been used for the surrounding stand. The area was planted at an original target stocking density of 2,500 stems ha^{-1}. However, the actual stocking rate is 2,850 stems ha^{-1}. The mean DBH of the plot is 9.8 cm (11.7 cm when only stems with DBH >7 cm are considered), a basal area of 30.2 m^2 ha^{-1} (27.4 m^2 ha^{-1} with DBH >7 cm) and 12.6 m top height. The stand had been rated as General Yield Class 8. The stand was of relatively poor quality but there was sufficient quality stems to identify and mark 200 potential crop trees (PCTs) ha^{-1}. Extraction racks were marked at 1:10 lines (approx. 20 m apart). Four crown competitors of each PCT were then marked; some identified competitors were in the racks. Due to the exposure of the site, it was considered too risky to remove more than four crown competitors per PCT. In the majority of cases any remaining trees adjacent to the PCTs were either suppressed or sub-dominants so would have had relatively little competitive impact on the PCTs. The free-growth operation reduced the basal area to 18.3 m^2 ha^{-1} (17.0 m^2 ha^{-1} with DBH >7 cm). The racks, which included some competitors, had a basal area of 1.5 m^2 ha^{-1} (0.7 m^2 ha^{-1} with DBH >7 cm). The DBH of all remaining stems and height of the PCTs is being monitored each year and it is intended that the trial will continue to be monitored and managed after the conclusion of the B-SilvRD project. The objective of the trial is to demonstrate the system and to attain a PCT target diameter within the shortest time period possible. However, the trial is not a replicated experiment so

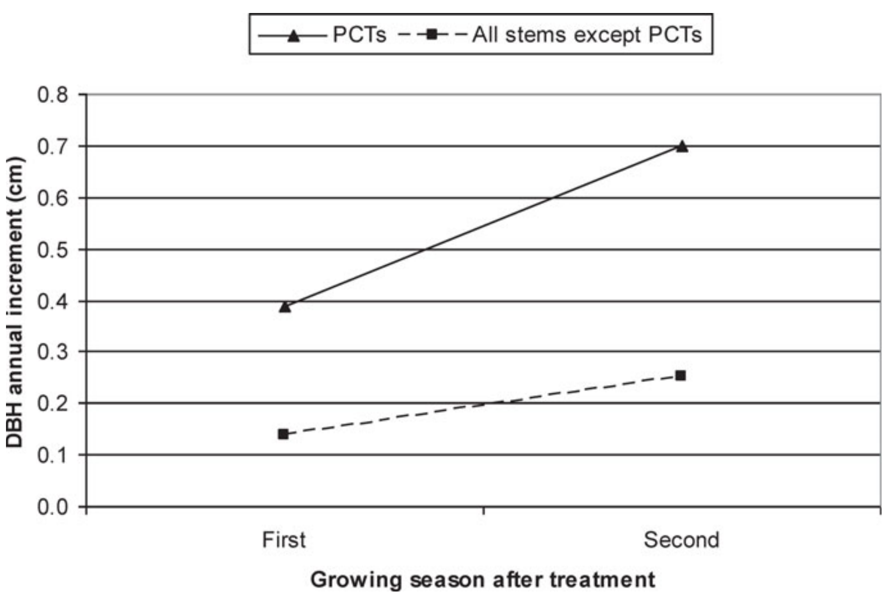

Figure 7: *Annual diameter at breast height (DBH) increment of Potential Crop Trees (PCTs) and matrix trees of a modified free-growth system in 19-year-old ash, Co. Mayo.*

the data must be interpreted cautiously. It is hoped that other similar trials will be laid down in the future, thus allowing a more robust evaluation of treatment effects.

Erdmann et al. (1985) estimated that red maple in America managed with regularly scheduled crop tree release thinnings could result in a stand with mean DBH of 45.7 cm within 85 years. Without release, an additional 42 years would be required to produce similarly sized trees. It is hoped that a similar effect will result in the current trial. The mean annual DBH increment of the first two growing seasons subsequent to the free-growth treatment being applied to the current trial, is illustrated in Figure 7. With a regular continued free-growth management practice being applied it is hoped that the PCTs will continue to exhibit increased DBH growth and attain the target diameter as quickly as possible.

Conclusion

A number of studies have concluded that the free-growth system has the potential to reduce the rotation length of broadleaf stands. The established view of the system seems to be that it is not suitable for oak because of the additional labour required to control epicormic shoots. However, an economic model that used a British free-grown oak yield model casts doubt on the validity of this widely held belief. A free-growth system is being recommended for oak in France. In pole-stage broadleaf stands where there are only a limited number of evenly-distributed stems suitable for selection as potential crop trees, the free-growth system may be the best option that is likely to result in a productive stand. The B-SilvRD pilot trial will, given time, provide useful information for the management of such poorly performing stands and will inform the design of any future fully replicated trial for a robust reappraisal of the free-growth system.

Recommendations

A reappraisal of the free-growth silvicultural system is warranted as it may have potential to improve the productivity and economic viability of poorly performing pole-stage broadleaf stands and the free-growth system should be considered for a number of broadleaf species, including oak.

Acknowledgements

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Tracking the impact of afforestation on bird communities

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Abstract
Studies of the impact of afforestation on biodiversity typically rely on surveys conducted at planted and unplanted sites at a single point in time. This paper reports on surveys of bird diversity in unplanted grassland sites and repeat surveys at the same sites seven years after afforestation and is the first longterm experiment of this type for Ireland. Birds were chosen for this study as they are easily surveyed indicators of biodiversity that respond well to environmental change. Overall, species richness was higher in the young forest plantations than in the pre-planting open grassland sites and this increase was a result in the increase in shrub cover following the cessation of grazing in these sites after afforestation. Some farmland bird species were absent following afforestation, but these were replaced by forest-associated bird species. Wren (*Troglodytes troglodytes*) and warbler (Sylviidae family) species benefited the most from afforestation, though other research suggests that the long-term impact of afforestation on many of these species will be less positive. This study highlights the requirement for long-term investment in biodiversity monitoring following land-use change. Scientific studies of this kind support the integration of biodiversity maintenance with timber production, which is a goal of national and global afforestation policies.

Keywords: *Afforestation, biodiversity, birds, forest management, grassland*.

Introduction

Afforestation refers to the establishment of a forest or stand in an area where the preceding vegetation or land-use was not forest (Helms 1998). Although forest cover in the island of Ireland was once extensive, deforestation over the past few thousand years has resulted in just 1% of native forest cover remaining by 2008 (Cross 2012). Ambitious afforestation targets have been set by the Irish government since the introduction of the Forestry Act of 1946. Despite not always having met these targets (Malone 1998, COFORD Council 2009), Ireland had the highest afforestation rate in Europe between 1990 and 2007. Nonetheless, Ireland's current forest cover remains well below the European average, at under 12%, with just over 80% of this being plantation forest, compared with an average of 30% forest cover throughout most of the rest of Europe (ITGA 2012). The Irish government currently has a target to achieve a national forest area of 1 million ha (circa 14.5% of land area) by 2030 through further afforestation. In addition to the provision of habitat,

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forests provide employment and are central to our future "green" economy, as a means of increasing carbon capture and as a renewable energy resource (COFORD Council 2009).

The success of afforestation is measured not only by how well it meets economic objectives, but also by how it contributes to social, aesthetic and environmental requirements (Renou and Farrell 2005, Carnus et al. 2006). One of the major issues in developing sustainable forestry in Ireland is ensuring that the industry does not negatively impact on biodiversity. Conservation has a constraining effect on afforestation in Ireland through environmental legislation and efforts to comply with Sustainable Forest Management. To this end, the current Afforestation Grant and Premium Scheme in Ireland incorporates biodiversity considerations, and the Forest Biodiversity Guidelines focus on how to conserve and enhance biodiversity through appropriate planning, conservation and management (An Taisce 2011).

Research results have demonstrated that afforestation may have either a positive or negative impact on biodiversity, the magnitude and direction of which is influenced by the land use that preceded forest planting and by local forest management practices and the tree species planted (Hunter 2000, Carnus et al. 2006, Marquiss 2007, Brockerhoff et al. 2008, O'Connell et al. 2012). When planted in areas of low biodiversity value, such as intensively-managed agricultural land, plantation forests offer the potential to enhance biodiversity and protect species through the provision of habitat (Freedman 2007, Iremonger et al. 2007, Brockerhoff et al. 2008) for at least a portion of the forest cycle. For many decades, commercial afforestation was confined largely to Ireland's uplands for economic reasons. However, increases in the importance of the uplands for conservation, amenity and wind energy, combined with agricultural reforms and an increased interest in planting diverse mixtures of conifers and broadleaved trees, has meant that afforestation is increasingly taking place at lower elevations, and also on private rather than public lands, where it now competes with food production as a land use.

Ireland supports some internationally significant populations of birds and possesses some notable woodland subspecies such as jay (*Garrulus glandarius hibernicus*) and coal tit (*Periparus ater hibernicus*) (Nairn and O'Halloran 2012). Of 199 bird species assessed in Ireland, 25 were on the Red list, 85 on the Amber list and the remaining 89 on the Green list (Lynas et al. 2007). Red is the highest conservation priority, with species needing urgent action, amber include species of moderate conservation concern, whereas green-listed birds are not threatened.

Forests are important habitats for birds, and although Irish forests possess fewer bird species, and in particular woodland specialists, than found in the rest of Europe (Fuller et al. 2007), they support a large number of bird species, including several of conservation concern (Lynas et al. 2007, Nairn and O'Halloran 2012).

Bird species are protected at European level under the EU Birds Directive (209/147/EC) and at national level under the Wildlife Act 1976 and The Wildlife (Amendment) Acts 2000–2010. Afforestation impacts on biodiversity through a diverse, interacting array of mechanisms such as changes to food and breeding resources, dispersal opportunities and physiological tolerance limits (Gardner 2010).

Birds are useful indicators of biodiversity as they are typically positioned near the top of food chains, are responsive to environmental change, their populations are readily surveyed and their biology is well understood (Furness and Greenwood 1993). Therefore, the impact of afforestation on the biodiversity of bird communities is of interest to forest managers and policy makers alike.

Despite political and scientific interest in the impact of afforestation on biodiversity, few direct studies have been conducted to date. Studies of the influence of afforestation have typically been indirect in nature, examining biodiversity in forest plots at different stages of the afforestation cycle (chronosequences) at different locations (Moss et al. 1979, Newton and Moss 1981, Pithon et al. 2005, Wilson et al. 2006, Freedman 2007, Marquiss 2007). Such studies have aimed to detect temporal trends from studies of different aged sites and are conducted due to necessity or convenience (Pickett 1989). However, they cannot overcome the potential confounding effect of biotic and abiotic differences in replicate sites. The impact of afforestation at five forest sites in Ireland that Iremonger et al. (2007) established as long-term monitoring plots during the BIOFOREST project, was assessed in this study by direct comparison of bird communities at the sites before and after planting.

Materials and methods

Study sites

Five grassland sites, all designated for afforestation were selected for use in this study. These sites comprised agriculturally improved and wet grassland habitats (GA1 and GS4 in Fossitt 2000), which are the main habitat types currently undergoing afforestation in Ireland. The sites were located at Garyandrew (Co. Tipperary), Kilbraugh (Co. Kilkenny), Coolsnaghtig (Co. Cork), Donaghmore (Co. Laois) and Mullanmeen Under (Co. Fermanagh). These sites were planted in 2003 with an intimate mixture of conifer and broadleaf trees with the exception of Mullanmeen Under which was only planted with Sitka spruce (*Picea sitchensis* Bong.). Sites were afforested according to the Republic of Ireland Forest Service Guidelines and UK Forest Commission Guidelines, both of which require a minimum of 10% of the area to be retained as open space for biodiversity conservation. The tree species planted and other site details are outlined in Table 1.

Bird diversity surveys

Bird surveys were conducted in 2002, before the sites were planted, and seven years after planting in 2010. Surveys were carried out using point counts (Bibby et al. 2000), during which birds were counted for 10 minute periods from fixed positions. All birds seen and heard within 50 m of the observer were recorded and their distances from the observer estimated subjectively. A minimum of six point counts were located at each study site. Points were placed at a minimum of 100 m apart and positioned to incorporate internal and external field boundaries. The same point locations were surveyed before and after afforestation at each site. Bird surveys were conducted only during good weather conditions and not in heavy or persistent

Table 1: *Details of the location, size, grassland type and tree species planted at each of the five study sites that were sampled pre-afforestation and seven years post-afforestation.*

Site	Location	Area (ha)	Grassland type	Tree species planted
Garyandrew, Co. Tipperary	7° 50' 29.3"W 52° 28' 10.5"N	17.0	Improved	Ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.)
Kilbraugh, Co. Kilkenny	7° 33' 35.3"W 52° 38' 35.3"N	20.7	Improved/ wet	Japanese larch (*Larix kaempferi* Lam.), Sitka spruce (*Picea sitchensis* (Bong.) Carr), alder (Alnus glutinosa L.)
Coolsnaghtig, Co. Cork	9° 8' 35.4"W 51° 45' 0.5"N	6.2	Wet	Ash, oak (*Quercus petraea* (Matt.) Liebl.), Spanish chestnut (*Castanea sativa* Mill.), European larch (*Larix decidua* Mill.), Japanese larch, Sitka spruce, alder
Donaghmore, Co. Laois	7° 36' 14.9"W 52° 52' 5.6"N	11.9	Wet	Japanese larch, Sitka spruce, alder, ash, sycamore
Mullanmeen, Co. Fermanagh	7° 45' 0.3"W 54° 35' 14.0"N	29.5	Wet	Sitka spruce

rain, or in winds greater than Beaufort scale 4, as the detectability of many bird species is severely reduced in persistent rain or in windy conditions (Bibby et al. 2000).

In each of the two sampling years, each point was surveyed twice: once early in the breeding season (April–May) and once later (May–June). Each site was visited twice to decrease the risk of missing either early or late breeding species, which might be absent or relatively undetectable during one of the visits. Counts were carried out during the period from two hours after sunrise to two hours before sunset, to avoid sampling around dawn and dusk when bird singing activity typically peaks, which could confound comparisons between sites. Timing of visits was varied such that all points received one visit in the morning and one in the afternoon in each sampling year. Individuals that were detected in flight were excluded from analysis as their presence does not necessarily indicate a breeding association with the habitat over which they are flying.

Habitat recording

The results of previous Irish research has identified that the shrub cover and tree cover components of habitat vegetation have strong influences on bird communities

(Wilson et al. 2006, Sweeney et al. 2010a). Therefore, the percentage cover of deciduous trees, conifer trees and of shrubs were recorded within a radius of 50 m at each sampling point in each year. Shrub cover was defined as all woody vegetation from 0.5 to 2.0 m in height, not including the commercial tree crop.

Data analysis

The data collected during point counts were used to derive estimates of bird density (numbers of individual birds ha^{-1}) and species richness (cumulative number of species) at each survey point. Distance software was used to derive species densities from field observations (Buckland et al. 2001). This was necessary because the detectability of birds differed between species and habitats. Estimation of densities using Distance is a standard method in ornithology that allows more reliable comparisons of numbers across different habitats and species. The conservation value of each site was estimated as the sum of the density of each species recorded at a site divided by the estimated national abundance of that species (Crowe et al. 2011).

Differences in the conservation value, species richness and total bird density in addition to the recorded habitat variables, shrub cover, conifer tree cover and deciduous tree cover, between pre- and post-afforestation states at each individual sampling point were assessed using paired t-tests. Prior to performing all t-tests, normality and homogeneity of variance were tested using Kolmogorov-Smirnov and Levenes tests, respectively. Where assumptions of normality and /or homogeneity of variance were not met, differences between paired samples were tested using Wilcoxon's Signed Rank Tests. All univariate tests were conducted in PASW Statistic 18.

Generalised linear models using a Poisson distribution were used to identify those habitat variables related to species richness and conservation value at each sampling point. Variables in each analysis included conifer tree cover, deciduous tree cover and shrub cover. To adjust for site effects, site was included as an explanatory factor in all models. The overall impact of afforestation was included in the analyses, with treatment (before and after afforestation) included as a categorical variable. To determine the most important explanatory variables in the GLMs, model averaging was applied using the dredge function in the R library MuMIn.

Non-metric multi-dimensional scaling (NMDS) analysis was carried out to determine between-site patterns in the bird community assemblages using PC-ORD (version 6; MjM Software, Gleneden Beach, Oregon, USA) using Sørensen distance measures. All species which were recorded in <5% of the point count locations were excluded from the analyses.

Results

Thirty one bird species were recorded during the current study. Grey wagtail (*Motacilla cinerea)*, jackdaw (*Corvus monedula*), skylark (*Alauda arvensis*) and spotted flycatcher (*Muscicapa striata*) were all recorded at grassland habitats before planting, but not at afforested sites. Blackcap (*Sylvia atricapilla*), grasshopper warbler (*Locustella naevia*), goldfinch (*Carduelis carduelis*), hooded crow (*Corvus

Table 2: *Densities (individuals ha^{-1} ± SE) of birds recorded at sites one year before planting and seven years post-planting.*

	Pre-planting		Post-planting	
Common species				
Chaffinch (*Fringilla coelebs*)	1.45	(0.48)	1.33	(0.51)
Robin (*Erithacus rubecula*)	1.45	(0.38)	0.80	(0.28)
Wren (*Troglodytes troglodytes*)	0.62	(0.25)	1.79	(0.40)
Blackbird (*Turdus merula*)	0.92	(0.24)	0.95	(0.27)
Warblers				
Willow warbler (*Phylloscopus trochilus*)	0.41	(0.17)	2.29	(0.50)
Chiffchaff (*Phylloscopus collybita*)	0.21	(0.16)	0.81	(0.35)
Grasshopper warbler (*Locustella naevia*)	0.0	-	0.04	(0.04)
Blackcap (*Sylvia atricapilla*)	0.0	-	0.52	(0.20)
Hole nesters				
Coal tit (*Parus ater*)	0.51	(0.23)	0.6	(0.32)
Blue tit (*Parus caeruleus*)	0.62	(0.32)	0.53	(0.22)
Great tit (*Parus major*)	0.06	(0.06)	0.35	(0.16)
All other species	4.43	(1.39)	2.70	(0.54)
Total Bird Density	12.75	(2.75)	12.93	(1.82)

cornix) and lesser redpoll (*Carduelis cabaret*) were all recorded at afforested sites, but not at pre-afforested grassland sites. The most common bird species at pre-planting sites were chaffinch (*Fringilla coelebs*), robin (*Erithacus rubecula*), goldcrest (*Regulus regulus*) and blackbird (*Turdus merula*). Densities of chaffinches, robins and blackbirds remained relatively stable at sites following afforestation and the densities of wren (*Troglodytes troglodytes*) and warbler (Sylviidae) species increased (Table 2). A number of Amber listed species were recorded including spotted flycatcher and skylark at pre-planting grassland sites, grasshopper warbler at post-planted sites and kestrel (*Falco tinnunculus*) and swallow (*Hirundo rustica*) which occurred at these sites both before and after planting.

There was no significant difference in the density of birds ($z = -1.7$, $p = 0.09$) or the conservation value ($z = -1.52$, $p = 0.13$) of survey points before or after afforestation (Figure 1). However, there was a significant increase in bird species richness following afforestation ($z = 3.44$, $p = 0.001$) (Figure 1).

There were considerable differences in the habitat variables between pre- and post-afforestation (Figure 2). Shrub cover ($t = -5.9$, df = 31, $p < 0.001$), conifer tree cover ($z = 3.74$, df = 31, $p < 0.001$) and deciduous tree cover ($z = 3.55$, df = 31, $p < 0.001$) all increased significantly in the seven years following afforestation (Figure 2).

There was considerably more variation between individual bird communities in pre-afforestation grasslands sites in comparison to the post-afforestation bird assemblages at these same sampling locations. This is indicated by the wider spacing of the pre-afforestation sites in the NMS ordination space compared to the

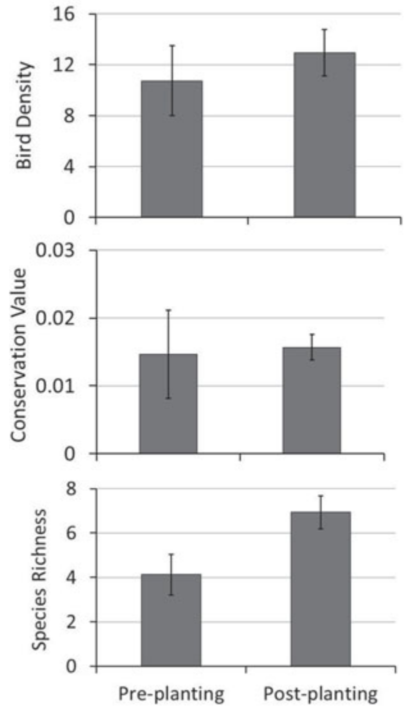

Figure 1: *Mean density of birds, number of bird species (species richness) and site conservation value in the study sites before and after afforestation*.

post afforestation sites, which occupy a relatively tight cluster. This indicates that bird communities in these sites become more homogenous following afforestation (Figure 3).

Results from the general linear modelling showed that the number of bird species recorded was positively related to afforestation and the amount of shrub cover within the habitat. There was no impact of site, conifer tree cover or

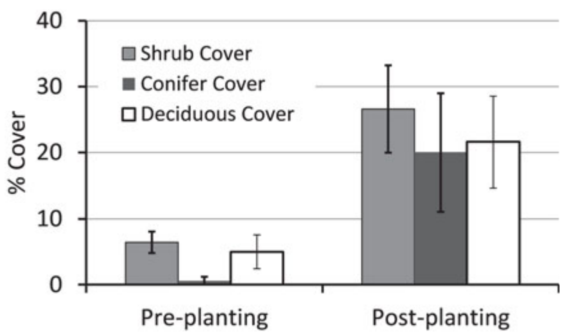

Figure 2: *Mean percentage of shrub cover and conifer and deciduous tree cover recorded one year pre-afforestation and 7 years post-afforestation*.

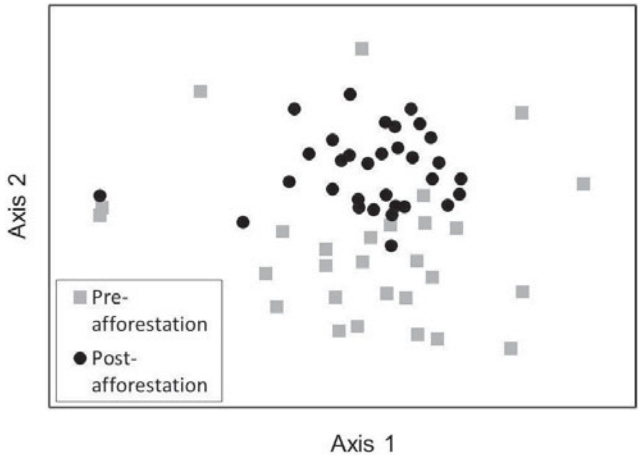

Figure 3: *NMS ordination of bird community data of the study sites pre- and post-afforestation. Variation accounted for by axis 1 = 44.2% and by axis 2 = 17.7%. Final stress for two-dimensional solution = 18.02; final instability = 0.00049 from 50 Monte Carlo simulation runs).*

deciduous tree cover on bird species richness (Table 3). None of the habitat variables measured had a significant impact on the computed conservation value metric of the study sites.

Discussion

Increasing national and global afforestation, combined with increasing constraints from conservation priorities means that now, more than ever, there is a need for data on the effects of afforestation on biological diversity. This is particularly true for birds, since almost all species are protected under the Wildlife Act (Wildlife Act 1976).

Studies of the effect of afforestation on biodiversity typically use "space-for-time substitution", which involves the extrapolation of a temporal trend from a series of different-aged samples from a single point in time to derive information on the possible effects of afforestation (Pickett 1989). This method is particularly useful in forest biodiversity research, where forest rotations are lengthy when compared to the typical duration of a research project. However, it is not always possible to elucidate temporal trends from such a chronosequence approach, due to results being confounded by abiotic and/or biological differences between sites. The value of long term tracking of biodiversity in recently established forest sites, such as in this study, is being increasingly recognised (Gardner 2010). The current study of bird diversity in Irish forests is the first analysis of the long-term impacts of afforestation on biodiversity in Ireland. Of the four bird species that were recorded only at unplanted sites, the grey wagtail, skylark and jackdaw are birds of open habitats. However, the Amber Listed spotted flycatcher is associated with both farmland and forest habitats (Nairn and O'Halloran, 2012) and its absence from afforested sites is noteworthy. The observed increase in density of birds post-afforestation was due primarily to increases in the numbers of a few key groups, particularly wren and warbler species. All of these birds commonly nest on or near the ground in herbaceous vegetation or low-lying brambles (Gibbons et al. 1993) and the decrease in grazing pressure as a result of afforestation (Marquiss 2007) most likely facilitated their increase. Willow warblers inhabit both woodland and farmland habitats (Nairn and O'Halloran 2012), but although they were relatively rare before planting, they were the most abundant species in the young forest plantations. Woodland-associated species such as blackcap, grasshopper warbler, goldfinch and lesser redpoll all benefited from afforestation of the grassland sites and were found exclusively post-planting. Long-term benefits for these species cannot be inferred from the results of the current study as the bird communities of plantation forests change as the trees mature (Wilson et al. 2006, Sweeney et al. 2010a), and the current study is confined to the effect of afforestation during the early stages of the forest cycle. Subsequent surveys of this site, as the planted forests mature, will be required to extend our understanding of the effects of afforestation to later forest growth stages.

In some situations afforestation is reported to be related to a loss of bird species (Newton 2004, Marquiss 2007). However, plantation forests can, in some contexts, offer opportunities for biodiversity conservation, particularly when forests replace biodiverse-poor land uses such as is the case for intensive agriculture (Hunter 2000, Carnus et al. 2006, Brockerhoff et al. 2008). In this study, a positive impact of afforestation on bird communities was demonstrated at the grassland sites through increased species richness. Surprisingly, no impact of site on the species richness or conservation value following afforestation was found. One might expect a more beneficial impact of afforestation at the improved grassland site (Garyandrew) as it had low habitat complexity pre-afforestation, relative to the wet grassland sites.

The positive impact of afforestation at this early stage of the commercial forest cycle is mediated through changes in vegetation structure. Pre-planting, improved grassland sites had little shrub or tree cover and were therefore lacking in vegetation structure, particularly in comparison to wet grassland sites. Bird diversity in Ireland is positively related to habitat complexity in plantation forests (Wilson et al. 2006, Sweeney et al. 2010a). Following afforestation, the development of shrub cover significantly enhanced the habitat complexity of the sites, making them attractive to a wider range of species than the homogenous short sward grassland it replaced. Pre-thicket forests therefore provide suitable habitat for species characteristic of semi-natural open habitats, and have the potential to increase biodiversity in intensively managed agricultural landscapes.

Table 3: *Summary output of the model-averaged parameter estimates from generalised linear models of bird species richness recorded at the study sites.*

Parameter	Estimate	Adjusted SE	z value	Significance (*p*)[a]
Intercept	4.50	1.420	3.18	0.0015
Afforestation	2.80	0.800	3.49	0.0005
Site	−0.50	0.811	0.62	0.5300
Shrub cover	0.05	0.024	2.28	0.0200

[a] Significant at 0.05 level.

However, although there was a significant increase in bird species richness following afforestation, ordination of the bird communities revealed a contraction of diversity between bird-community types following afforestation, as demonstrated by the restriction in ordination space occupied by the bird communities of planted sites. This resulted in the bird communities at sites becoming much more similar to each other post-planting than they were before planting. This is an important distinction as afforestation, up to the stage assessed, resulted in a loss of bird assemblage beta diversity (variation in communities between sites) .

The observed changes to bird communities of sites following afforestation may have been in part due to fluctuations in bird populations at a national scale over the seven years between sampling dates. However, as the observed changes were consistent with those anticipated from previous studies (e.g. Sweeney at al. 2010b, Wilson et al. 2010), it appears that the overwhelming factor affecting bird communities in this study was the impact of afforestation.

As these plantation forests mature, considerable changes in the bird communities may occur. Based on this past research, biodiversity of birds in Irish plantation forests is largely dependent on habitat complexity and in particular, the retention of shrub cover. Future monitoring of these sites is required to determine the impact of the maturing tree crop on the shrub cover within these sites and the resulting effects on bird communities.

Conclusions

The combined priorities of biodiversity and wood production are critical issues to be resolved for future afforestation in Ireland, and can be achieved through targeted management practices. Long-term investigations, such as was carried out in this study, are essential to inform policy in order to protect biodiversity over the plantation cycle.

Afforestation of grassland areas is likely to increase over the next decade or so. Tree planting in these areas should be staged to occur gradually over an extended period of time so that the resulting forest cover is uneven in age and structure, thus maximising biodiversity. Establishment of new forests in this way will help to ensure continued availability of pre-thicket forest habitats, which may be disproportionately important for bird diversity in some agricultural landscapes.

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Development of an individual tree volume model for Irish Sitka spruce and comparison with existing UK Forestry Commission and Irish GROWFOR models

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Abstract
The two most common models used to estimate tree volume in Ireland are the British Forestry Commission (FC) models, developed using British data and the Irish Growfor models developed from Irish stand data. Here, a model analogous to the British FC model for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is developed using individual Irish tree data and all models are compared. Sitka spruce data from Coillte Teo (Irish Forestry Board) stands in the Wexford and Waterford regions, consisting of 81 thinned plots with a total of 4,315 volume-sampled trees (5,419 trees including repeated measurements), were used for the study. Stepwise regression was carried out to select the model and a Box-Cox transformation was used to improve model fit. A 2k-fold cross validation was used to check the validity of the selected model across different subsets of the data. The selected model slightly over-predicts volume in its mean volume per ha estimate by 0.38%, whereas the GROWFOR estimate under-predicts by 4.6% and the British FC model under-predicts by 8.6%.

Keywords: *Stepwise regression, 2k-fold cross validation, subset comparison, Box-Cox transformation, mean squared predictive error.*

Introduction

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) is the main tree species in Irish forests accounting for approximately 52% of total forest area (National Forest Inventory 2007). Models are particularly useful when estimating individual tree volumes as they do not necessitate tree felling or extensive height and diameter measurements. The two main existing models used for estimating individual tree volume of Irish Sitka spruce are the British Forestry Commission (FC) single tree model for Sitka spruce (Hamilton 1985, Matthews and Mackie 2006) and the Sitka spruce model used in the Irish GROWFOR software that computes volume on a stand basis (Broad and Lynch 2006a).

More recently, dynamic models and spatio-temporal models have been developed to model tree growth, for example those developed by Fox (2007a, 2007b). This has arisen in response to more extensive data becoming available, for example through aerial photography (Dubayah 2000), GIS methodology (Plant 2012) and developments in statistical modelling. However, the models are not in a

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form that is readily available or usable by industry, e.g. via commercial software packages. Use of such models is also contingent on the provision of training regarding their use.

The Forestry Commission model for estimating individual tree volume is widely used in the UK and Ireland by commercial, government and industrial organisations. The model parameter estimates are published in the FC tables. The FC model is a single tree tariff system with the dependent variable, the single tree tariff number (TN) expressed in the British quarter girth system units, while the independent variables, diameter at breast height (DBH) and total height, are both expressed in metric units. The quarter girth units are converted to metric units that can then be used to read the tables (see Materials and Methods section).

The FC model and the model developed in this paper are static models in that they assume the stands are managed according to a prescribed thinning pattern as given by Matthews and Mackie (2006). The GROWFOR model is dynamic in that it does not assume prescribed management regimes. It relies on modelling incremental changes in the variables of interest over time. The multivariate extension of the Bertalanffy-Richards model (García 1994) is used for estimation and just requires data on a stand basis rather than an individual tree basis. The model takes into account the relationship between the stand and its variables by classifying the stand by its top-height – age relationship (i.e. site index class). The GROWFOR model for Sitka spruce was developed by Broad and Lynch (2006a) with the aim of developing an "alternative growth projection mechanism for Sitka spruce that is amenable to simulating a wide range of management alternatives specific to Irish conditions" (Ibid.).

Until recently, forest growth and yield modelling in Ireland was carried out using Forestry Commission Yield Models for Forest Management (Hamilton 1985). In the absence of Irish models, these models served the Irish forestry sector well. However, given the higher growth rates in Ireland compared to Britain, the use of these tables in Ireland is questionable. The inadequacy of these tables was further highlighted by Keogh (1985). Since 1999, the Irish forest industry, with support from COFORD (Council of Forest Research and Development) and Coillte Teo (Irish Forestry Board), led a project to develop dynamic yield models which are based on Irish research data (Purser and Lynch 2012). When Irish dynamic yield models were compared directly with British Forestry Commission (FC) models it was found that current volumes (i.e. where there is no growth projection) produced by Irish dynamic yield models are frequently greater. This may be attributable to a combination of factors including: 1. Irish stands show improved upper stem diameters due to improved growing stock and/or growth conditions; 2. FC volume estimates may have been prepared on a conservative basis due to mensurational techniques employed (*Ibid*.).

The objective of this study was to develop a model for estimating the individual tree volume of Irish Sitka spruce that was comparable to the FC model for individual tree volume, but developed specifically using Irish data and to compare this with the existing FC and GROWFOR models. Permanent sample plot data from Coillte stands in the Wexford and Waterford region were used in this study.

Materials and methods

The data

Coillte Teo (Irish Forestry Board) maintains the most extensive crop structure database on Sitka spruce in the Irish Republic. The database includes many silvicultural thinning and spacing experiments that have been repeatedly remeasured during the period 1963 to 2006. These experiments were established using repeated measurement experimental designs with the randomized block design being the most widely adopted approach. Plots that were measured repeatedly were considered permanent.

The Sitka spruce permanent sample plots were classified into seven regions throughout the country. The data used to develop the models were extracted from Sitka spruce thinned plots in counties Wicklow and Wexford. There were 81 plots in total distributed over eight locations (Table 1).

All of the data arose from thinned permanent sample plots. Any models fit to the data refer only to trees and stands where thinning has occurred. However, neither the thinning type, thinning intensity or thinning cycle were considered in this study.

Data from the 1971 to 2006 period were used. There were a total of 320 plot "visits", which included repeated measures on 81 plots. Plot sizes ranged from 0.0405 ha to 0.0809 ha. The trees in these plots were planted from 1943 to 1966. The plots were homogenous and contained only Sitka spruce.

The diameter at breast height (cm), measured at 1.3 m above ground-level, of all the trees in each plot were recorded at each assessment. The variable mean DBH is the quadratic mean diameter, i.e the square root of the sum of the DBH's squared (Matthews and Mackie 2006). Height (m) was measured on a subsample of the thinned trees and the maincrop trees after thinning. Within each plot there were trees for which data on upperstem diameters were also recorded at a specified number of points along the stem. The number of combined upperstem diameter-height measurements along the stem varied from 5 to 10, with 10 measurements being the norm and shorter trees having fewer measurements. From these the volume of the tree could be calculated. The total tree height (TOTH) of all these was also recorded. These trees are referred to as volume-sample trees. The age of each tree when measured or remeasured was also recorded.

Table 1: *Details of the Sitka spruce permanent sample plots in Wicklow and Wexford.*

	Location	Planting year	Property	No. plots
1.	Avoca	1943	Ballinvally	4
2.	Avoca	1953	Ballymoyle Hill	12
3.	Ballinglen	1966	Askakeagh	12
4.	Clonegal	1957	Coolmelagh	16
5.	Coolgraney	1947	Raheenleagh	4
6.	Coolgraney	1949	Raheenleagh	3
7.	Forth	1962	Cools	16
8.	Shillelagh	1951	Barnamuinga	14

For each plot a number of top height (m) measurements were made, where a "top height" tree "is the tree of largest DBH in a 0.01 ha sample plot" (Edwards and Christie 1981).

Stocking density (n ha^{-1}) was recorded, and the easting (E) (m), northing (N) (m) and elevation above sea-level (Z) (m) for each permanent sample plot were determined using mapping software ArcPad 10 and ArcGIS 10.

Model fitting

The 81 sampled plots consisted of 14,283 trees in total. The volume-sample tree data containing the sectional lengths and diameters were extracted from the dataset for 4,315 trees, including repeated measurements. This consisted of 5,419 measurements in total. The sectional diameters (d) were converted to cross-sectional areas ($CSA = \pi(d/200)^2$) (m^2). The sectional volumes (m^3) were calculated using Smalian's formula for the volume of the frustum of a paraboloid (Avery and Burkhart 1994). The sum of the sectional volumes is considered a reasonable estimate of the true individual tree volume.

A series of regression models were fitted with the aim of identifying the variables that are significant for the individual tree volume (m^3) estimates. The dependent variable was individual tree volume (VOL) and the explanatory variables considered were DBH, tree height (HT), tree age (years), plot stocking density (n ha^{-1}), approximate plot eastings, northings and elevation. Following a graphical analysis of the relationships between VOL and these variables, the quadratic and cubic terms of DBH and HT and the interaction between DBH and HT were also considered in the model. Nested models were fitted by adding and dropping covariates in succession. These models were compared using their adjusted coefficient of determination (adj. R^2) where R^2 is adjusted for the number of explanatory terms in the model. Unlike R^2, the adjusted R^2 increases only if the new term improves the model more than would be expected by chance. The preferred model was chosen as the model with the highest adjusted R^2 value.

A Box-Cox transformation (Box and Cox 1964) was used to estimate an appropriate power transformation (λ) for the dependent variable, individual tree volume, to improve model fit. Volume estimates were also calculated from the data using the Forestry Commission and Irish GROWFOR models for Sitka spruce. The models were compared using their adjusted coefficient of determination (adj. R^2) and by comparing the approximate volume (m^3 ha^{-1}) estimates of the predicted values.

A 2k-fold cross validation was used to check the validity of the preferred model. The dataset was split retrospectively randomly into approximately two halves; the model was re-fit to one half and used to predict tree volume estimates on the other. Stepwise regression was carried out on the two halves to determine if the same independent variables were selected using the two half datasets. In addition, a regression was carried out using the variables selected for the original model, a model with new parameter estimates was fit to one half of the data, the training dataset. These parameter estimates were then used to predict tree volume estimates for the remainder of the data, the test dataset. The mean squared error of the training dataset was compared to the mean squared predictive error (MSPR) of the test dataset (Kutner et al. 2004):

$$\text{MSPR} = \frac{\sum_{i=1}^{n^*}(Y_i - \hat{Y}_i)^2}{n^*} \tag{1}$$

where Y_i is the value of the response variable in the i^{th} validation case, $\hat{Y}_i$ is the predicted value for the i^{th} validation case based on the model-building dataset, and n* is the number of cases in the validation dataset.

The process was repeated, using the training data instead of the test data and the test data instead of the training data.

The Forestry Commission (FC) model

The Forestry Commission single tree tariff system for pure even-aged stands allow tree volume to be calculated. The principle underlying this approach is that there is a linear relationship between basal area and volume; therefore, volume can be estimated from DBH (Matthews and Mackie 2006). It does not provide an estimate of individual tree volume directly but rather estimates the tariff number for any individual Sitka spruce tree as a function of the DBH and the total height. The domains over which the single tree tariff model is applicable are:

- $8 \leq \text{DBH} \leq 80$ (cm)
- $8 \leq \text{TOTH} \leq 40$ (m)

A fundemental issue persists with the FC single tree tariff system in that the dependent variable, the single tree tariff number (TN), is expressed in the British quarter girth system units, while the independent variables DBH and total height are both expressed in metric units.

The TN refers to a pre-constructed volume-basal area equation each of which has two predefined volume-basal area coordinates. The first predefined volume-basal area coordinates correspond to minimum volume and minimum basal area i.e. (0.005 m^3, 0.03848 m^2). The second predefined volume-basal area coordinates correspond to the volume (m^3) associated with the tariff number and the basal area associated with one square foot quarter girth, i.e. (0.036054 TN m^3, 0.118288 m^2).

Having estimated the TN, the slope (b_1) (m^3/m^2) and intercept (b_0) (m^3) associated with the pre-constructed local volume-basal area model can be estimated. The volume of an individual tree is estimated using the estimated parameters of the local volume-basal area model and the basal area of the individual tree. Using information from Matthews and Mackie (2006), the Forestry Commission preconstructed metric single tree model for estimating Sitka spruce individual tree volume (m^3) can be calculated as follows:

$$\text{Individual tree volume} = b_0 + b_1\text{BA}(m^2) \tag{2}$$

where basal area (BA) = $\left(\frac{DBH}{200}\right)^2$

$$b_0 = -\,0.004882 - 0.002147(HT) + 0.000505(DBH)$$
$$b_1 = \;\; 2.568687 + 0.558008(HT) - 0.131221(DBH)$$

The FC individual tree volume was estimated for each volume-sample tree using Equation 2.

Irish GROWFOR software

GROWFOR is Irish forest dynamic yield software that estimates current timber volume ($m^2\ ha^{-1}$) when a specific plot input vector is provided. The input variables per plot are: species, age, stocking density ($n\ ha^{-1}$), top height and basal area ($m^2\ ha^{-1}$), or mean DBH - the mean DBH over all trees in a plot.

Input vector estimates from 320 Sitka spruce permanent sample plots, 81 plots with repeated measurements, were input individually into GROWFOR. Note GROWFOR estimates are made on a unit area basis and not an individual tree basis.

Results

Model fitting

Table 2 shows eight models that were fit to the data subset consisting of volume sample trees only (n = 5,419 volume sample trees) and their adjusted R^2. The independent variables in Model 2 (FC_{IRISH}) are the same as those that occur in the reparamaterized Forestry Commission single tree volume model derived previously.

Diameter at breast height is a good predictor of tree volume; the inclusion of the quadratic terms DBH and tree height in model 5 gave a high adj. R^2 of 0.9798. Including HT (tree height), age and interaction terms between HT and DBH led to

Table 2: *The table shows individual tree volume models for Irish Sitka spruce for a selection of models with associated adjusted R^2.*

Model	Variables in the model	Adj. R^2	
1	VOL = DBH, DBH^2, DBH^3, HT, HT×DBH, HT×DBH^2, AGE, AGE^2	0.9889	
2	VOL = DBH, DBH^2, DBH^3, HT, HT×DBH, HT×DBH^2	0.9885	FC_{IRISH}
3	VOL = DBH, DBH^2, HT, HT×DBH	0.9875	
4	VOL = mDBH, DBH^2, mDBH×DBH^2, mHT, mHT×DBH^2	0.9833	
5	VOL = DBH, DBH^2, HT	0.9798	
6	VOL = DBH, HT	0.8690	
7	VOL = AGE, AGE^2, E, N, Z	0.6360	
8	VOL = AGE, AGE^2	0.6313	

where VOL = tree volume , DBH = diameter at breast height (cm), HT = total height (m), AGE = tree age (years), mDBH = mean diameter at breast height of all volume sample trees in a plot (m), mHT = mean height of all volume sample trees in a plot (m), E = easting (m), N = northing (m) and Z = elevation above sea level (m).

an improved fit. Only variables with a significant p-value were retained in any of the models. Model 2 (FC_{IRISH}), which contains the same variables as the Forestry Commission individual tree model, but not the same parameter estimates, has an adj. R^2 of 0.9885. There is an increase from 0.9813 to 0.9885 using the newly estimated coefficients instead of the FC coefficients (Table 5).

When HT and DBH were in the model, E, N and Z were not significant and therefore were omitted. Similarly, HT^2 and the stocking density were not significant.

Model 1 is similar to model 2, except it includes the linear and quadratic term of tree age. This only led to a slight increase in the adj. R^2, but the variables were significant and were retained. Although the differences in the adjusted R^2 values are small, these become important, in practical terms, when tree volume is converted to volume per hectare.

The residual variance for these models (Table 2) increased as volume increased (Figure 1). Figure 2 shows the model fit less well for the smallest and largest volumes. A Box-Cox transformation (Box and Cox 1964) was applied to transform the dependent variable volume. The "best" lambda (λ) was estimated at 0.25 for all models containing DBH and height (models 1–6) and at 0 for models excluding DBH and HT (models 7 and 8). Table 3 shows the back-transformed adjusted R^2 for models 1 and 2, with the highest adjusted R^2 values and model 8, to show the effect of the transformation on a model excluding DBH and HT.

Therefore, root 4 of tree-volume ($VOL^{0.25}$) was used as the dependent variable for models 1 and 2, and log(VOL) for model 8. The improvement in the residual variance can be seen in Figures 3 and 4. Four observations were removed from the

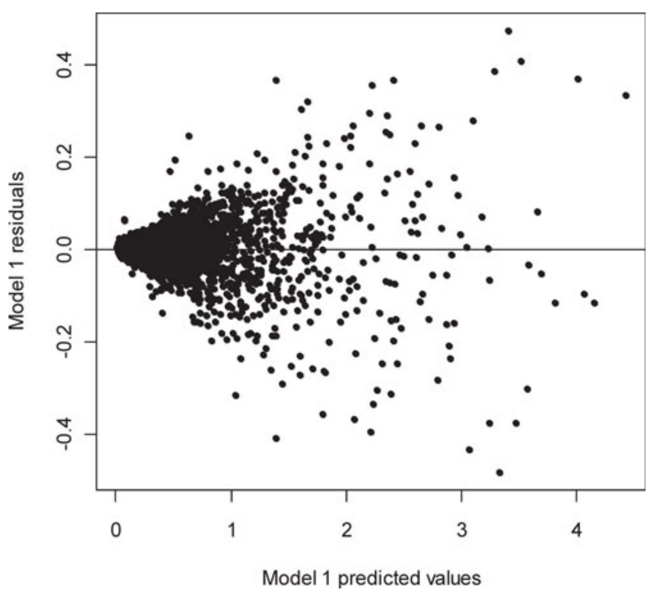

Figure 1: *The plot shows the residuals versus the predicted values of individual tree volume (m^3) for model 1 defined in the text. Model 1 is the best fitting model to observed tree volumes of Sitka spruce in the Wicklow region, based on diameter at breast height, height and age.*

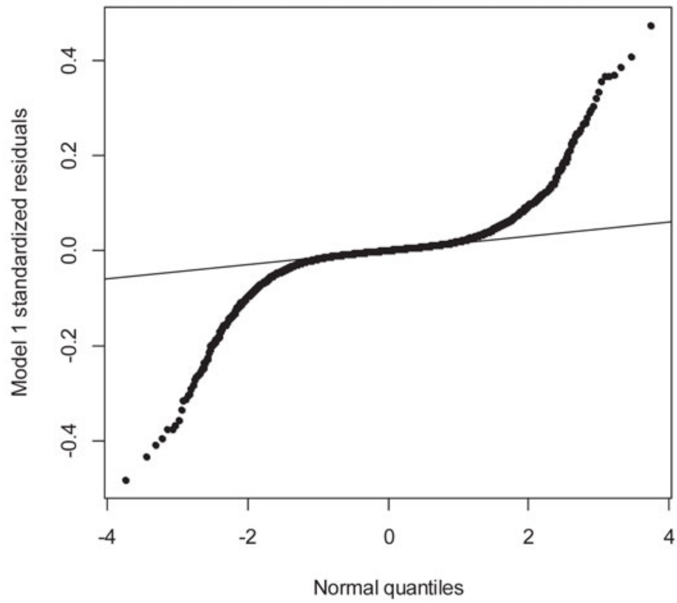

Figure 2: *A normal q-q plot of the standardised residuals from model 1 defined in the text. Model 1 is the best fitting model to observed tree volumes of Sitka spruce in the Wicklow region, based on diameter at breast height, height and age.*

data as outliers. The adjusted R^2 and back transformed adjusted R^2 for the transformed models are presented in Table 3.

The Box-Cox model 1 contains the same independent variables as model 1, except the dependent variable is volume$^{0.25}$. The back-transformed adjusted R^2 was 0.9901, which is a slight increase from 0.9889 in Table 2. Similarly, the Box-Cox model 2 has the same variables as model 2 and the back-transformed adjusted R^2 of 0.9898, which is a slight increase from 0.9885. There were very small increases in the back-transformed adjusted R^2; however, the variance of the residuals did not increase in proportion to the mean (Figure 3) and thus inference using least squares estimation, which requires constant variance, is valid.

There is a decrease in the back-transformed adjusted R^2 from model 8 compared

Table 3: *Models with the dependent variable (volume) transformed.*

Box-Cox model	Model variables	Adj. R^2 (not back transformed)	Adj. R^2 (back transformed)
1.	$VOL^{0.25}$ = DBH, DBH^2, DBH^3, HT, HT×DBH, DBH^2×HT age age^2	0.9942	0.9901
2.	$VOL^{0.25}$ = DBH, DBH^2, DBH^3, HT, DBH×HT, DBH^2×HT	0.9940	0.9898
8.	Log(VOL) = age, age^2	0.6233	0.6078

where DBH = diameter at breast height (cm), HT = total height (m), AGE = tree age (years) and VOL = tree volume (m^3).

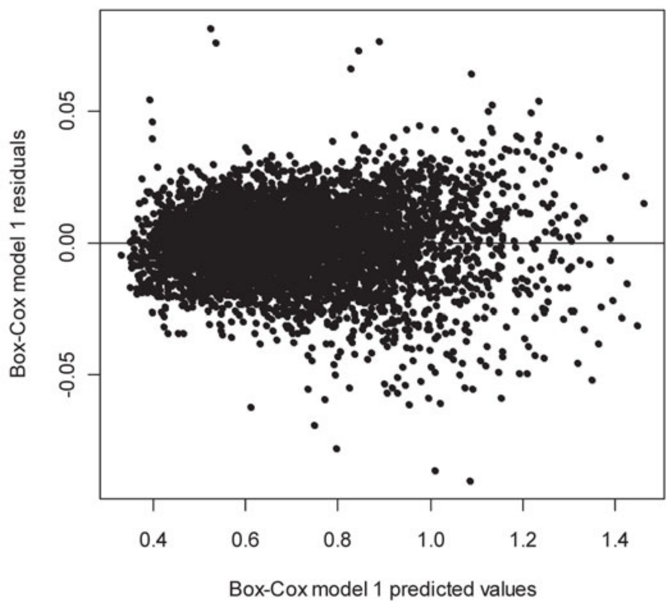

Figure 3: *The plot shows the residuals versus the predicted values of individual tree volume (m^3) for Box-Cox model 1 defined in the text. Box-Cox model 1 is the best fitting model, with a Box-Cox transformation, to root 4 of the observed tree volumes of Sitka spruce in the Wicklow region, based on diameter at breast height, height and age.*

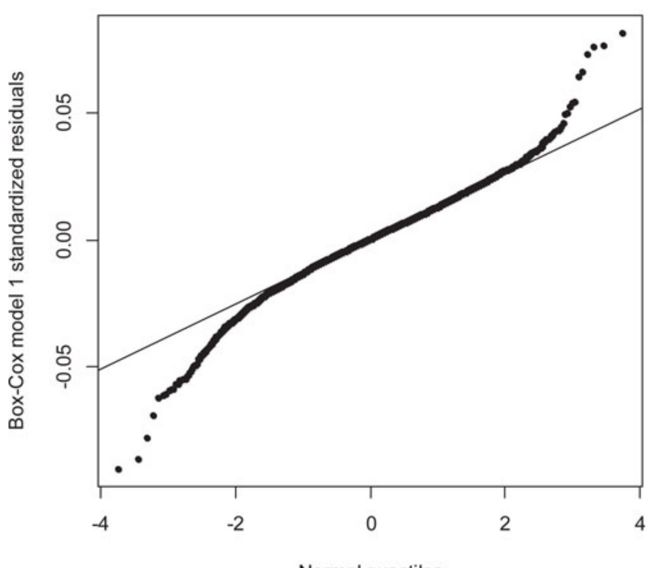

Figure 4: *A normal q-q plot of the standardised residuals from Box-Cox model 1 defined in the text. Box-Cox model 1 is the best fitting model, with a Box-Cox transformation, to root 4 of the observed tree volumes of Sitka spruce in the Wicklow region, based on diameter at breast height, height and age.*

Table 4: *Box-Cox single tree model 1 parameter estimates.*

	Parameter	Estimate	Standard error	t-value	Pr > |t|
β_0	Intercept	0.0376366284	0.00399242	9.43	<0.0001
β_1	DBH	0.0308911823	0.00033019	93.56	<0.0001
β_2	HT	0.0109354768	0.00053631	20.39	<0.0001
β_3	DBH^2	−0.0003524884	0.00001775	−19.86	<0.0001
β_4	DBH^3	0.0000008792	0.00000031	2.80	0.0051
β_5	DBH×HT	−0.0001484999	0.00003902	−3.81	0.0001
β_6	DBH^2×HT	0.0000041729	0.00000067	6.18	<0.0001
β_7	age	0.0030090328	0.00019115	15.74	<0.0001
β_8	age^2	−0.0000453409	0.00000294	−15.42	<0.0001

where DBH = diameter at breast height (cm), HT = total height (m) and AGE = tree age (years).

to the Box-Cox model 8; however as before, the distribution of the residual variance is random.

Box-Cox model 1 has the highest adj. R^2 and the residual variance does not increase in proportion to the mean, therefore, it is considered the "best" model of the models considered above. The parameter estimates are shown in Table 4 and the equation is as follows:

$$(\text{Tree Volume})^{0.25} = \beta_0 + \beta_1(DBH) + \beta_2(DBH^2) + \beta_3(DBH^3) + \beta_4(HT) + \beta_5(DBH \times HT) + \beta_6(DBH^2 \times HT) + \beta_7(age) + \beta_8(age^2) \quad (3)$$

The Box-Cox model 1 predicted versus the actual tree volumes are plotted in Figure 5. Clearly there still is more variability associated with larger volume estimates. It appears the model does not over- or under-estimate volume, given that there is an even distribution on either side of the fitted line.

The Forestry Commission mean volume and volume per hectare estimates

The percentage differences between actual tree volumes and the FC tree volume estimates (VOL_EST_{UK}) were calculated as a percentage of the actual tree volumes. The average difference was 12%; however, this varied from year to year. It should be noted that the average difference decreased in later years, i.e. as tree-age increased.

Figure 6 shows a plot of VOL_EST_{UK} versus VOL. Many of the tree volume estimates from the FC model are below the line of equality suggesting the FC model under-estimates tree volume. The adj. R^2 for the FC_{UK} model is 0.9813.

The 320 mean volume per ha (mVOL_ha) estimates are shown in Table 5 to further compare the models. The volumes estimated using Box-Cox model 1 were closest to the actual volumes from the volume-sample trees. The Forestry Commission model per hectare estimates were approximately 8.6% lower than the volume-sample tree estimates.

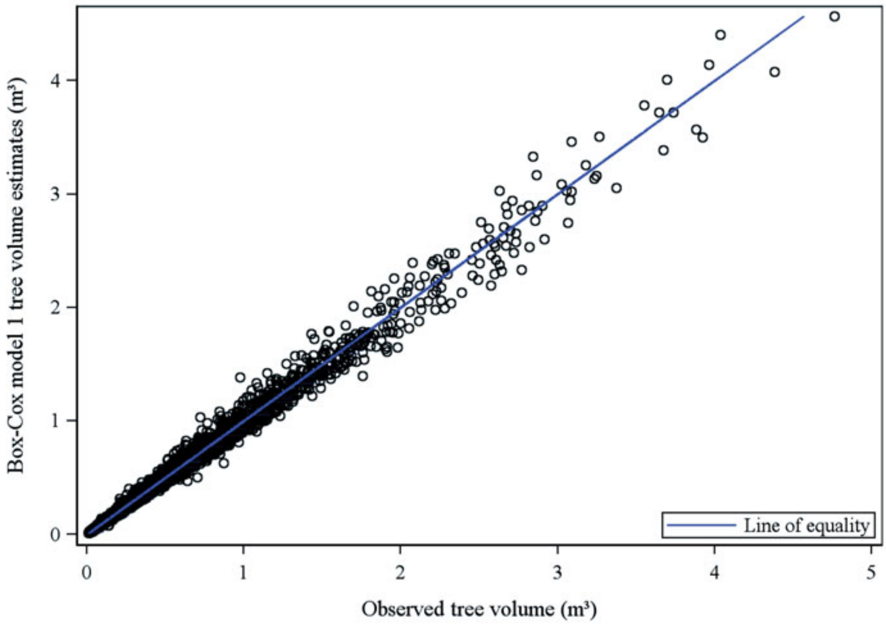

Figure 5: *Predicted values of the best fitting model (Box-Cox model 1), with a Box-Cox transformation, to root 4 of the observed tree volumes of Sitka spruce in the Wicklow region, based on diameter at breast height, height and age were obtained. In the figure these are plotted against observed tree volumes (VOL).*

GROWFOR estimates

Using the GROWFOR input vector for a plot, i.e. age, stocking, top-height and mean DBH, the output, i.e. the VOL_ha estimates, for each plot were computed and stored in a separate file.

The mean and total volume per hectare estimates from GROWFOR were approximately 4.6% lower than the observed per hectare estimates. It may be argued that these are not comparable since the projections from GROWFOR are stand-based. However, it is worth noting that the GROWFOR estimates did better than the Forestry Commission volume per hectare estimates. Figure 7 shows GROWFOR volume per hectare estimates versus the observed volume per hectare estimates; the points below the fitted model illustate that the GROWFOR estimates tended to be lower than the observed volumes.

Table 5: *Volume estimates by model.*

Model	Adj. R^2	Mean Vol_ha estimate (SE) (m^3 ha^{-1})
Actual observed volumes		397.1 (10.7)
Box-Cox model 1	0.9901	398.6 (10.8)
GROWFOR		378.7 (10.3)
Forestry Commission	0.9813	363.1 (11.0)

where SE = standard error.

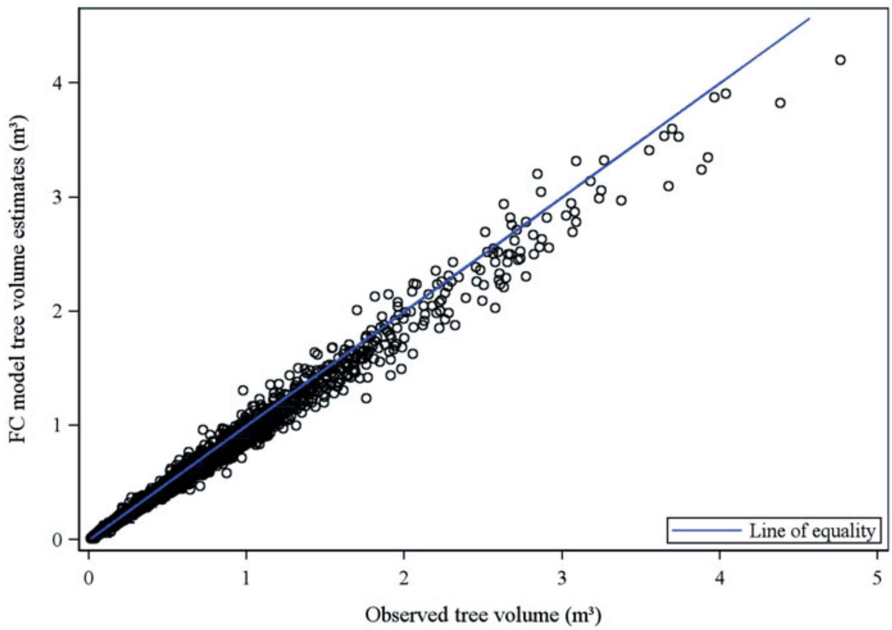

Figure 6: *Predicted values of the forestry commission model of the response variable observed tree volume (VOL_EST_{UK}) of Sitka spruce in the Wicklow region, were obtained. In the figure these are plotted against observed tree volumes (VOL).*

Subset comparison

The Irish individual tree models above were fitted to the entire dataset. As a validation method for Box-Cox model 1, the dataset was split retrospectively and randomly into approximately two halves to carry out cross validation of the data. Each half contained 160 plots and will be referred to as D_A (2,157 trees) and D_B (2,187 trees).

Stepwise regression was carried out separately on D_A and D_B, with all of the variables discussed in the results (model fitting) section included, with $VOL^{0.25}$ as the dependent variable. In the case of D_B, the same variables were selected as those in the Box-Cox model 1. In the case of D_A, all the variables that were in Box-Cox model 1 were chosen except DBH×HT, the interaction term between DBH and tree height. However, since DBH^2×HT was chosen, both terms were kept in the model in accordance with the hierarchy principle. In both cases, D_A and D_B, the models selected are consistent with Box-Cox model 1. Therefore, in the comparison below all variables of Box-Cox model 1 were used for prediction. The variables from Box-Cox model 1 were fitted to D_A, providing a new set of parameter estimates. These were used to calculate predicted estimates of tree volume for D_B. The mean squared error (MSE) from D_A and the mean squared predictive error (MSPR) from D_B are presented in Table 6.

The MSE for D_A is 0.002627 and the MSPR for D_B is 0.002552. The fact that the

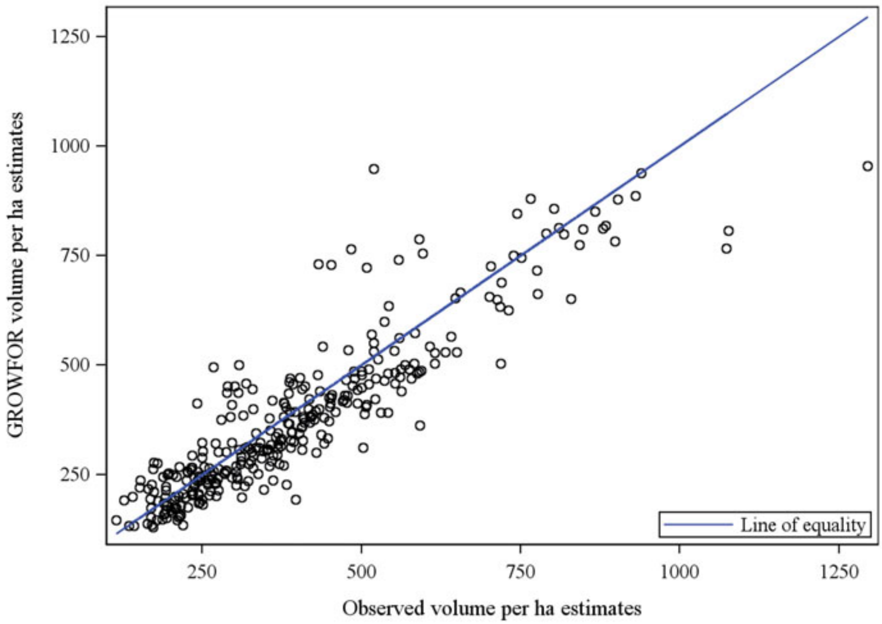

Figure 7: *Volume estimates (m^3 ha^{-1}) for 320 Sitka spruce plots in the Wicklow region were obtained using the GROWFOR software. In the figure these are plotted against the observed volumes.*

MSPR is close to MSE implies that the MSE based on the training data set is a valid indicator of the predictive ability of the fitted regression model.

The process was repeated with D_B as the training data and D_A as the test data. The variables from Box-Cox model 1 were fit to D_B, providing a new set of parameter estimates which were used to calculate predicted estimates of tree volume for D_A. The MSE from D_B and MSPR from D_A are shown in Table 7. When using D_B for the training data, the MSE of the model fit is 0.002311, the MSPR for D_A is 0.003164. As above, the fact that these values are close suggests the MSE for D_B is a reasonably valid indicator of the predictive ability of the fitted regression model. The fact that the MSE and MSPR values are not very different is not surprising

Table 6: *Fit statistics for the training data (D_A) and predicted fit statistics for the test data (D_B). The residual sum of squares (SSE), the mean squared error (MSE) and the mean squared predictive error (MPSR) are provided.*

	D_A training data	D_B test data
Adj. R^2	0.9889	0.9901
SSE	5.6441	5.5586
MSE	0.0026	
MSPR		0.0026

Table 7: *Fit statistics for the training data (D_B) and predicted fit statistics for the test data (D_A). The residual sum of squares (SSE), the mean squared error (MSE) and the mean squared predictive error (MPSR) are provided.*

	D_B training data	D_A test data
Adj. R^2	0.9911	0.9866
SSE	5.0344	6.7963
MSE	0.0023	
MSPR		0.0032

since the training and test data were subsets of the same large dataset. However, it supports the validity of the model fit to these data.

Discussion

The 81 plots from which the data were collected plots established for the purposes of research by Coillte. They were used by Broad and Lynch (2006a) to develop dynamic yield models for Sitka spruce, and made available in GROWFOR. In a subsequent paper, Broad and Lynch (2006b) found that sampling in Coillte research plots has been skewed towards higher productivity stands. Defining site index as the top height at age 30 (*Ibid.*), there were no experimental plots in the lower two site index classes in the Coillte estate. Therefore, any models fit to these data are representative of the site index distribution associated with research plots.

One issue with this dataset is that it contains repeated measures. Data from the 81 plots were collected over a 35-year period, with each plot revisited approximately four or five times. The selection procedure followed was always the same over time as specified by the experiment protocol. Some volume-sample trees were measured once only, while some were measured up to three times. Repeated measurements, from the same tree, are not independent and are therefore correlated. However, in like manner, repeated measurements from different trees are independent and uncorrelated. This issue was not accounted for in the present model and may lead to underestimation of standard errors in estimates in the fitted models. For comparison purposes, with the FC and GROWFOR models, the correlation from repeated measurements was not investigated.

The eastings, northings and elevations were excluded from models that included DBH and HT as they were not significant, suggesting a plot's location did not affect the volume of its trees. However, values of E, N and Z were the same for all trees in a plot and individual tree GIS co-ordinates were not available for analysis. Thus, while there were no large scale spatial effects, on a smaller scale they may have existed.

While the issues discussed above (i.e. bias in the data and repeated measures) need to be considered, for this research dataset Box-Cox model 1 had the highest adjusted R^2 and the best fit. It over-predicted mean volume per ha estimates (Table 5) by 0.38%, but was better than the GROWFOR estimates which under-predicted by 4.6% and the FC model which under-predicted by 8.6%. For a forest of 100 ha size, the estimated timber volume (using the observed tree volumes) would be 397,100 m^3. Using the Box-Cox model 1, the predicted volume would be 398,600 m^3. Using the GROWFOR and FC models the predicted volume would be 378,100 m^3 and 363,100 m^3, respectively. This leads to a difference of 20,500 m^3 and 35,500 m^3, respectively, which may be significant in terms of commercial timber value. Note that these models assume a pre-determined management regime.

The Box-Cox model 1 requires the age, DBH and height of a tree to estimate volume. While the age of a tree is usually recorded and the DBH is easily measured, height is usually only measured on a subsample of trees. This might no longer be the case with new methods of measurements, such as lidar remote sensing technology and other methods, which has demonstrated the capability to accurately estimate important forest structural characteristics (Dubayah 2000).

Further analysis could be carried out to investigate the presence of spatial effects and the effects of thinning, if individual tree locations were available. In the present model time is accounted for by age of the tree. The data could be modelled over time, as the trees grow, producing a more dynamic model. This is very important for forecasting and predicting tree volume.

Currently forests are seen as ecosystems and developments continue to progress in relation to their management application subject to associated changing rules from regulatory bodies. In addition, climate change plays an increasing role in forest management and associated production. Thus, while here only a static model has been considered it may provide a basis on which more general models may be built. It may also be useful in itself as changes may occur too rapidly to be incorporated in a general model.

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Soil carbon stocks in a Sitka spruce chronosequence following afforestation

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Abstract
Increasing concentrations of CO_2 and other greenhouse gases in the atmosphere are leading to concern worldwide due to their contribution to the greenhouse effect. As the body of evidence supporting the need for change from a carbon rich economy/society becomes stronger, international mitigation agreements require high quality and precise information. Following the Kyoto Protocol and EU agreements to reduce carbon production, countries could utilise default values or comparable international data to calculate their carbon budgets. Initially, approximations were successful for generating a guide to a national carbon stock for reporting GHG inventories to the UNFCCC (Tier 1). However, now that the second phase of the Kyoto protocol is running until 2020, greater accuracy is essential and, where possible, nationally specific information is increasingly required (Tier 3, UNFCCC). Forestry and forest soils are seen as a key component in the carbon cycle and depending on their management, can mitigate or contribute to GHG emissions. Litter and soil organic matter (SOM) are two of the major carbon pools required for reporting under LULUCF. In this study, stocks of SOM and litter were recorded along a chronosequence of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) on wet mineral gley soil. Over a 47-year period, the rate of soil carbon sequestration was found to be 1.83 t C ha^{-1} yr^{-1}. Soil microbial biomass was used to estimate highly active SOM. The mineral soils were also fractionated in a density separation procedure to identify light and heavy SOM pools. These estimates can now be used to model carbon budgets of this most common soil type currently under forestry in Ireland.

Keywords: *Carbon, forest, soil microbial biomass, density fractionation*.

Introduction

Globally, the store of carbon (C) in soils is 3.5 times that of the atmosphere and almost five times that of the biosphere (Lal 2008) and, in forests, over two-thirds of the C is contained in soils and associated peat deposits (Dixon et al. 1994). The amount of C stored in the soil is the balance between inputs of organic material from the biota, which depends on the type of vegetation and its productivity at a particular site, and losses, primarily through soil microbial respiration (Zerva et al. 2005). Forests continuously recycle C through photosynthesis, respiration and mineralisation.

However, the net sequestration of C in vegetation, and especially in soil, can range over time periods from years to centuries. Forest soil C stock is controlled by factors such as previous land use (grasslands, cropland etc), tree species, soil cultivation method, soil properties (clay content), stand age, site management,

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topography and climatic zone. Estimates of its size are affected by the methodological approaches used in its estimation (Jandl et al. 2007, Laganière et al. 2010). The residence time of stable fractions of SOC (soil organic carbon) can be >1000 years (von Lutzow et al. 2006) making it a much more stable sink than living plant biomass (Laganière et al. 2010).

Forest soils represent a major C store with stocks exceeding those under most other land-uses, so the stability of this store is of obvious importance to climate change mitigation. Forest management practices that disturb the soil can lead to C loss while climate change can have both positive and negative impacts. Global warming and rising CO_2 levels in the atmosphere can enhance forest growth, which in turn could increase soil organic matter through greater litter input. Conversely, increasing soil temperatures are predicted to promote microbial activity and therefore decomposition and loss of soil organic matter (Coûteaux et al. 2001).

Within the United Nations Framework Convention on Climate Change (UNFCCC 1992) each signatory nation must report its C budgets via the greenhouse gas (GHG) inventory. The rules of land-use change and forestry (LULUCF) are particularly relevant to this topic. Initially, Tier 1 approximations (relatively low accuracy) were successful for generating a guide to a country's C stock for reporting. Now that the second phase of the Kyoto protocol (Kyoto Protocol, 2012) is running until 2020, greater accuracy is required in calculations and, where possible, Tier 3 level information is required. Article 3.3 of the Kyoto Protocol allows changes in C stocks due to afforestation, reforestation and deforestation since 1990 to be used to offset inventory emissions. With the recent increase in afforestation in Ireland, this sector has the potential to offset some of the national GHG emissions.

To understand the dynamics of soil organic matter (SOM), the amounts and the chemical nature of the inputs into the system need to be quantified. The mass, the N and C and lignin content of the litter are measured. These measurements are known to indicate the decomposability of the litter (Berg et al. 1993) and the quality of the SOM produced from this litter (Berg and Ekbohm 1991, Lavelle et al. 1993).

Soil microbial biomass can be a limiting factor in the nutrient cycle, as the vast majority of organic matter (~95% in conifer forest) must pass through microbial tissue in the process of decomposition and mineralisation (Huhta and Koskenniemi 1975, Jenkinson 1977, Petersen and Luxton 1982). High microbial activity indicates balanced nutrient availability and a more readily decomposable litter source (Vance and Chapin 2001). The potential activity of the SOM can be estimated by initially calculating the soil microbial biomass at a site. Therefore, measurement of the C and nutrients contained in the microbial biomass provides a basis for studies of the formation and turnover of soil organic matter, as the microbial biomass is one of the key definable fractions (Ocio and Brookes 1990, Ocio et al. 1991).

SOM is often divided into active, slow and passive pools (Parton et al. 1987) and quantifying the relative proportions of these provides an indication of the lability and stability of the soil C pool. A rough approximation to the distribution of the organic matter into these pools can be achieved through density fractionation (Christensen 1987a,b, 1992). The light fraction contains a considerable part of the active pool; it contains plant debris, spores, seeds, animal remains and mineral particles adhering to organic fragments. It has high microbial activity and high rates of turnover (Gregorich and Ellert 1993). The rapid mineralisation of the soil's light fraction can be related to the soil microbial biomass; therefore, it is a good estimation of the active fraction of the soil (Janzen et al. 1992). The heavy fraction is considered to be organomineral-complexed SOM which is taken to be comparatively more processed decomposition products with a narrow C:N ratio and a slower turnover rate (Christensen 1992).

Isotopic tracers have been used to show that the light fraction has two or more C pools with differing turnover rates (active and slow). The light fraction is however, sensitive to changes in the active organic matter pool, indicating its substantial presence (Bonde et al. 1992). Thus the light fraction is seen as a transitory SOM pool dominated by decomposing plant and animal residues with a relatively high C:N ratio. It has a rapid turnover containing a large proportion of microbes.

The objectives of this study were: (1) to quantify the change in soil C stock during the life cycle of a Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forest crop; (2) measure litter quantity and quality; (3) estimate microbial biomass; (4) estimate soil light and heavy fractions; and (5) assess the impacts of afforestation on soil C stocks using the chronosequence method. The results from this study were compared with values from the literature to determine their usefulness in generating predictions in the Irish scenario since unfortunately there are large knowledge gaps in relation to Irish forests.

Materials and Methods

The estimation of the rate of C sequestration in Irish forest soils was carried out using the chronosequence technique (Schlesinger 1990). The C content in the soil under stands of different age was measured and an average soil C increment calculated per year. A chronosequence can be seen as a space-for-time substitute enabling estimation of successional sequestration - that is substituting similar soils/site conditions (space) to obtain a chronosequence of different ages (time) (Allison et al. 2005). In selecting the location of the chronosequence, efforts were made to ensure the sites were as similar as possible, i.e. stands growing under similar environmental and management conditions, with similar soil type, topography, exposure and drainage.

Site description

The main study was located at Dooary Forest, Timahoe, Co. Laois in the Irish midlands, 52° 57’ 00” N, 7° 15’ 00” W. The 30-year mean annual temperature for this area is 9.3°C with a mean rainfall of 850 mm and an elevation of ~260 m. The site was previously unmanaged grassland but was planted largely with single species stands of Sitka spruce at a density of ca. 2,500 stem ha^{-1}.

Within the forested area, four stands were chosen to represent a chronosequence (a reconstructed historical age distribution) of Sitka spruce. The stands were aged 9, 14, 30 and 47 years when sampling began in 2002 (henceforth referred to as D9, D14, D30 and D47, respectively). They were representative of the typical yield class

(18–22 m^3 ha^{-1} yr^{-1}) for Sitka spruce growing on wet mineral soils in Ireland. The D14 stand had a higher than average yield class of 24 m^3 ha^{-1} yr^{-1} (Tobin and Nieuwenhuis 2007).

An adjacent grassland site was selected to represent a non-forested stand (G0) to assess changes in C sequestration associated with land-use change and the development of the forest. The D9 site had an open canopy at the commencement of the project, with grasses growing in-between and underneath the trees.

The D47 stand was felled in 2002 before any meaningful litterfall collection or microbial biomass measurements were made. A substitute site was then chosen for the litterfall and microbial biomass measurements, which was located in Cullenagh Forest (C45) directly to the north of Dooary. This forest was 45-years-old and also had a yield class of 22 m^3 ha^{-1} yr^{-1}.

Soil description

The soil is described as being associated with the Raheenduff Series with pockets in the Imperfectly Drained Phase according to *Soils of County Laois*, from the National Soil Survey of Ireland (Conry 1987). Surveys carried out of the forested area indicate that 90% of the soil is gley with 10% brown earth/podsol mixture. The soil is principally a wet surface-water mineral gley. Mean sand, silt and clay contents of the chronosequence soils were 22%, 36% and 42% respectively; pH was 4.6 and bulk density was 1.018 g cm^{-3} (Saiz et al. 2006, 2007). The C45 site had a sand, silt and clay content of 20, 50 and 30% respectively and a pH of 4.3. It had a bulk density of 1.063 g cm^{-3}. This soil was classified as a gleyic brown earth (Saiz et al. 2006). These figures mirror those described in the national soil survey (Conry 1987).

Soil core measurement

Fifteen randomly located soil cores were taken in each stand. The corer was a steel cylinder (5 cm diameter and 30 cm length). The soil was separated into litter, organic and mineral layers visually on site and placed into plastic bags. The soil was refrigerated on the day of collection and processing took place the following day.

Woody debris larger than 1 cm in diameter, stones and living plant and animal material was removed from the soil which was passed through a 5.6 mm mesh. The fresh weight of the soil was then recorded. Two 10 g subsamples were taken from the mineral and organic layers for microbial biomass analysis using the chloroform fumigation technique (Vance et al. 1987). Another 20 g subsample was removed from both layers and was processed for density fractionation. After the subsamples were removed, the remainder was oven dried for 48 hours at 80 ºC, or until weight became constant. The soil was then ground using a pestle and mortar and mixed thoroughly. The moisture content (%) was calculated. A 1 g sample was then taken from each layer and combusted at 540 ºC for two hours.

The percentage loss on ignition was then calculated and a conversion factor of 0.58 (Allen 1989) was used to convert organic matter to C content per gram of soil. Total C content of the soils at each site was estimated for each of the organic and upper mineral horizons based on loss on ignition, which was calibrated using CHN analysis. Loss on ignition was also calculated for the standing litter layer.

Litter measurements

Litter input was measured each month using litterfall collectors at each site in the chronosequence between 2002 and 2004. In each site, a 30 × 30 m plot was selected (away from boundaries to reduce edge effects). Twenty-five litter collectors (25 l plastic buckets of 28 cm diameter) were randomly located within the plot. Each bucket had a 15 cm nail through the centre of its base to secure it to the soil. Four 10 mm holes were drilled in the base of the bucket to allow drainage. Litter was collected once a month for two years from each of the five sites.

The litter was then dried for two days at 60 °C and separated into green needles, dead needles and twig/branch material. For the grassland site, litter estimates were made using the harvest technique of Sims et al. (1978). The same technique was used to estimate the increase in grass litter due to canopy closure in the D9 site. In this instance, a 0.25 m^2 quadrant was placed randomly in each plot and all standing vegetation was harvested. This material was dried as above and separated into live and dead material and weighed.

Litter samples were ground for 10 minutes at 900 oscillations per minute using a Retch grinder (Type MM2) until a homogenous powder was formed. The C, N and lignin content of the litter inputs were measured twice at each site of the chronosequence. The C and N concentrations were measured using a CHN analyser. A ground sample was flash combusted at 1,500 °C, followed by gas chromatography in an Exeter Analytical CE440 elemental analyser. All other monthly litter collections were combusted for percentage loss on ignition and total C content was calculated via a conversion constant relative to the previous measurements on the CHN analyser.

The lignin content was estimated following the methods of Allen (1989):

$$\text{Lignin (\%)} = (\text{corr. Lignin} \times \text{tot.} \times 10^2)/(\text{wt. for water extract} \times \text{sample wt.}) \quad (1)$$

where corr. lignin is corrected lignin. The ash and N-content was calculated for the crude lignin sub-samples. The N value was then multiplied by 6.25 to correct for crude protein. The crude protein and ash was then subtracted from the crude lignin before the lignin % calculation. tot. is the total ether-extracted lignin from the sample.

Microbial biomass C

The chloroform fumigation-extraction method (Vance et al. 1987) was used to measure the microbial biomass C in the soil. This method determines the microbial C by estimating the difference between fumigated and non-fumigated soil samples. Four sub-samples of soil were obtained from each soil unit, two from the mineral horizon and two from the organic horizon (approximately 10 g dry weight equivalent each). Biomass C was calculated using the following equation:

$$\text{Biomass C} = (\mu\text{g C g}^{-1}\text{ soil (fumigated)} - \mu\text{g C g}^{-1}\text{ soil (non-fumigated)}) / 0.45 \quad (2)$$

The proportion of microbial C evolved as CO_2 = to 0.45 for 10-day incubations at 25 °C (Jenkinson and Ladd 1981)

Density fractionation

Denstity fractionation separates macro organic matter from the mineral components of the soil (Six et al. 2001). This was done using water or heavy liquids, such as in this case sodium polytungstate (SPT) that are of greater density than the organic matter. The floating particles are considered as the light fraction (Christensen 1992). The light and heavy C fractions were separated following the methods of Compton and Boone (2002) which uses centrifugation and a liquid with a density of 1.6 g cm^{-3}. The resulting heavy and light materials were dried, weighed and ground. The C and N content of each fraction was measured using a CHN analyser. The total stock was estimated by multiplying the C and N concentrations by the weight of the original samples (which were area-based).

Results

Soil C stocks

The stocks of C in the soil varied considerably between the closed canopy sites in the chronosequence, but generally increased with time and were always greater than 100 t C ha^{-1} under a closed canopy (Figure 1). Generally the increase in soil C stocks over time varied between 0.2 to 1.8 t C ha^{-1} yr^{-1}. The lower C stock and greatest stock changes occurred in the D30 stand (Figure 1), which had a sloping topography, was more exposed and had lower soil moisture content. In contrast, the higher accumulation of soil C in D9, D14 and D47 stands may have been associated with the flatter topography and higher soil moisture contents.

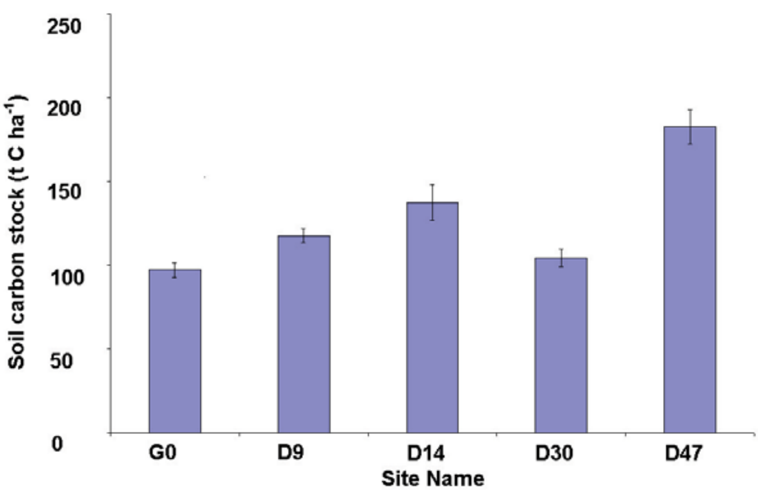

Figure 1: *Total soil C (t C ha^{-1}, ± S.E.) in the combined mineral and organic layers at each site in the chronosequence.*

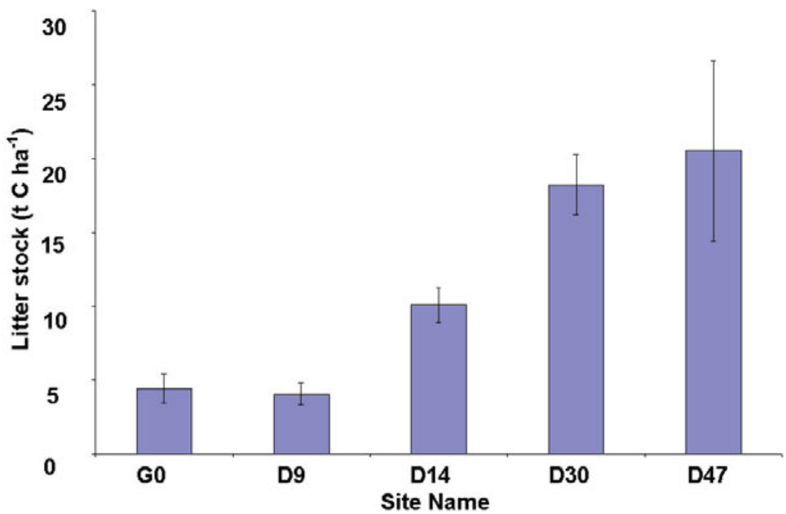

Figure 2: *Standing litter (forest floor) at each site in the chronosequence (t C ha^{-1}, ± S.E.).*

Litter C stocks

The standing litter in each site increased with age. There was an accumulation on the forest floor especially with the onset of canopy closure where the rate of decomposition was less than that of litterfall. In the youngest site D9, there was still living under-storey vegetation and an open canopy, which partially explains the lack of accumulation at this site. The oldest site (D47) had greatest variation due in part to standing water and patches of bare soil where no litter had accumulated (Figure 2).

Density fractionation

The heavy fraction of the soil increased over the chronosequence, 76 t C ha^{-1} in the G0 site to 153 t C ha^{-1} in the D47 site, whereas the light fraction fluctuated between 18 and 36 t C ha^{-1} (Figure 3). The heavy fraction at the D47 site was found to be a third or more greater than at the other sites, ~150 t C ha^{-1} versus ~ 100 t C ha^{-1}. The light fraction was very similar in the two youngest sites G0 and D9 (20 and 16 t C ha^{-1}), increased at the D14 site (32 t C ha^{-1}) and then stabilised at the two older sites (23 and 29 t C ha^{-1}).

Litter inputs

Litter input was measured at the four forested sites in the chronosequence. Monthly litter C inputs tended to be greatest from March to May associated with resumption of metabolism leading up to the time of bud burst (Figure 4). The input was greatest in 2002/2003 in the 14-year-old site as canopy closure had resulted in all the needles of the lower branches dying and no thinning event had occurred. In 2003/2004 all sites had increased litterfall rates, particularly the closed canopy sites (D14, D30 and C45). C45 was felled in September 2004 and no further litterfall values were obtained.

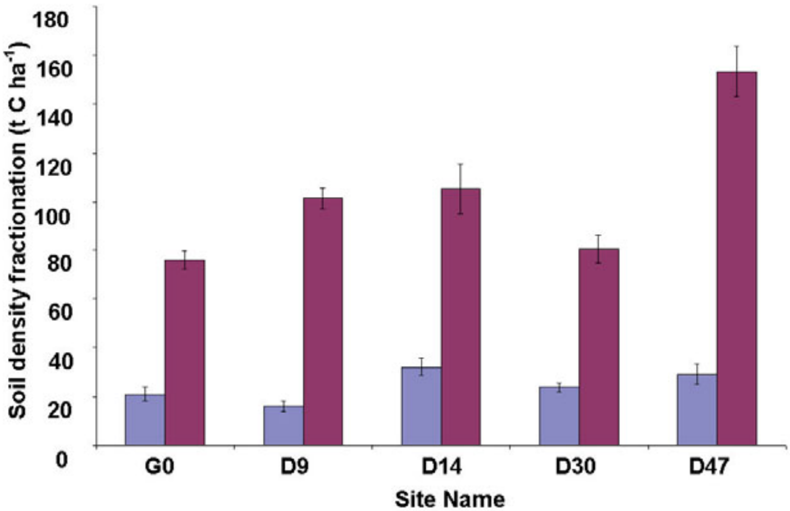

Figure 3: *Separated light (blue) and heavy (maroon) soil fractions (t C ha^{-1}, ± S.E.) at each of the sites in the chronosequence at Dooary.*

The largest annual input (4.04 t C ha^{-1} yr^{-1}) was recorded in the 14-year-old site (Figure 5). The closed canopy sites had more than double the cumulative litter of the open canopy site (D9) and grassland site (G0). This reflected the fact that almost all needles attached to branches were still alive at D9, with little or no senescence on lower branches. This resulted in a litter stock similar to G0 as the understory grasses were contributing the greatest proportion of the standing litter stock of D9. The

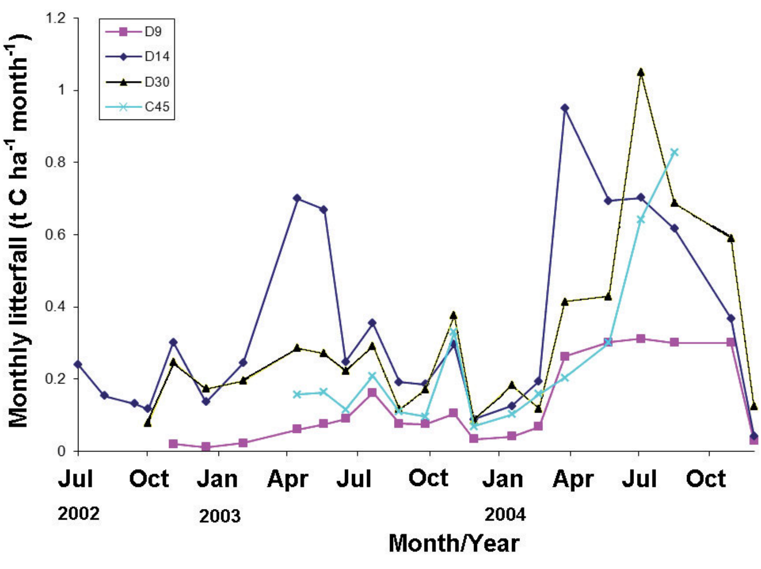

Figure 4: *Monthly litterfall at each of the four forested sites in Dooary (t C ha^{-1} month^{-1}).*

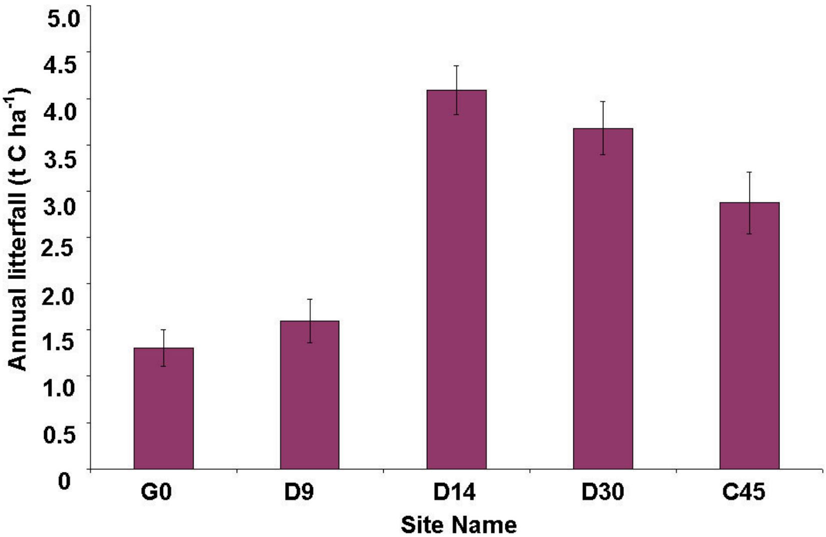

Figure 5: *Litter input for one year (2003/2004, ± S.E.) at the grassland site (G0) and four forested sites (D9, D14, D30 and C45) in Dooary (t C ha^{-1} yr^{-1}).*

annual litter input values for D9 (Figure 5) did not include the dead grass C input. This represented an additional C input of ca. 3 t C ha^{-1} yr^{-1}, based on a decrease in measured grassland biomass of 1.5 t C ha^{-1} yr^{-1} and a shoot to root ratio of 0.5.

The C, N and lignin contents of the litter inputs were estimated on three occasions over the 2-year period at all sites (Table 1). The four forested sites did not vary significantly for the litter quality variables. The grassland had slightly lower concentrations of C and N, 43.14% and 1.02% versus 47.12–47.94% and 1.06–1.37%. The grassland litter (G0) was more decomposed due to its better quality, with a narrower CN ratio and low lignin content which was ~25%, as distinct from >40% in the spruce needles.

Microbial biomass C

The greatest concentration of microbial biomass in the chronosequence was in the organic horizon in the grassland site, G0, 4,991 µg C g^{-1} dry soil which is over three times the next highest value of 1,427 µg C g^{-1} dry soil in the organic horizon of D30

Table. 1: *Quality of litter collected from the 5 chronosequence sites, % C, N and lignin in dry mass.*

Age	C	N	Lignin
G0	43.14	1.02	24.91
D10	47.12	1.14	41.79
D15	47.58	1.37	41.69
D30	47.94	1.10	40.10
C45	47.62	1.06	41.41

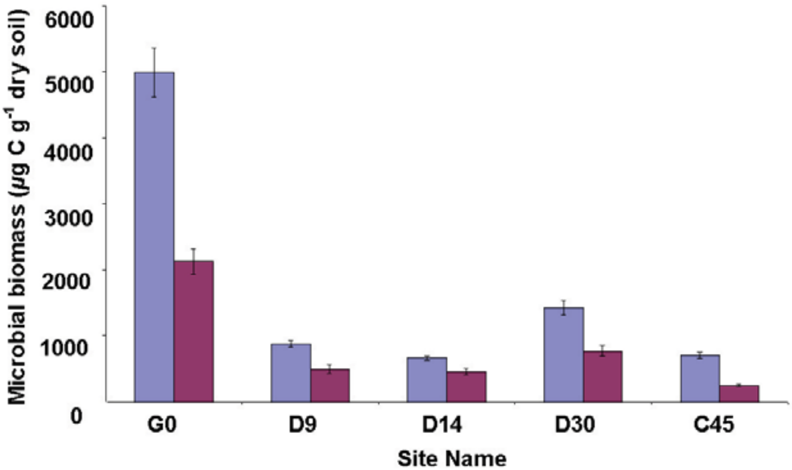

Figure 6: *Microbial biomass (µg C g^{-1} dry soi, ± S.E.) in organic (lilac) and mineral (maroon) soil horizons for the five sites in the Dooary chronosequence*.

(Figure 6). The organic horizon values for D9, D14 and C45 were quite similar to each other and were approximately half the concentration at D30. The greatest concentration of microbial biomass in the mineral horizon was again at the G0 site (2,127 µg C g^{-1} dry soil). This was much smaller than that contained in the G0 organic horizon. The same occurred at the D9, D14 and D30 sites, where organic horizon microbial biomass concentrations were approximately twice those in mineral horizons. The C45 site was different in that the concentration in the organic horizon was 705, compared to 244 µg C g^{-1} dry soil in the mineral horizon.

The amounts of microbial biomass present in the soil profile were calculated by combining the values above with the known weights of the soil. Across the chronosequence, the total stock of microbial biomass in both horizons was markedly different, with that in the mineral horizon being much larger, except at the D9 site where the amounts were similar (Figure 7 A). The large amount of microbial biomass in the G0 site is further emphasised when the site totals are compared across the five sites (Figure 7 B). The G0 site contains 362.8 g C m^{-2}, which is three times the amount in the D30 site (128.9 g C m^{-2}) and in the D9 site (121.4 g C m^{-2}).

Discussion

The total soil C stocks increased from 97 t C ha^{-1} in the grassland site to 183 t C ha^{-1} in the 47-year-old stand of Sitka spruce (Figure 1) which indicates that Sitka spruce plantations on this soil type have a potential to sequester approximately 80 t C ha^{-1} over the lifetime of a crop. This represents a sequestration rate of 1.83 t C ha^{-1} yr^{-1}, which is high in comparison to some other studies; e.g. 0.34 t C ha^{-1} yr^{-1} on acidic soil after 57 years under Norway spruce in Italy (Thuille and Schulze 2006) and 0.36 t C ha^{-1} yr^{-1} on a pseudogley soil under Norway spruce in Demark (Vesterdal et al. 2002). The higher accumulation at Dooary may be expected given the relationship between factors such as rate of productivity and decomposition

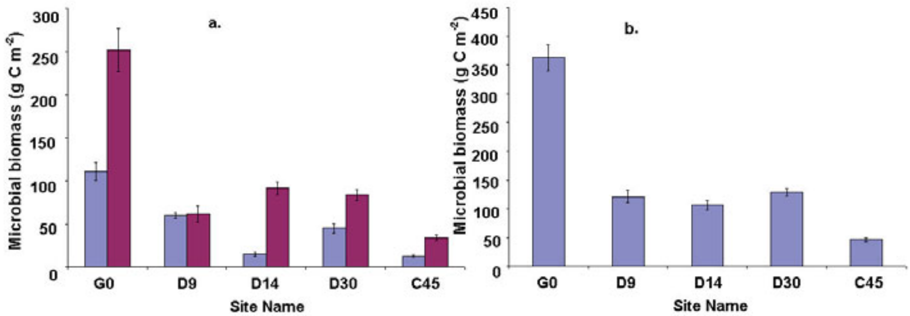

Figure 7: *Soil microbial biomass (g C m^{-2}, ± S.E.), for the five sites in the chronosequence in* ***a)*** *separate organic (lilac) and mineral (maroon) horizons and* ***b)*** *from the total soil profile*.

across Europe (Berg et al 1993, 1999, Bottner et al. 2000, Coûteaux et al. 2001). In higher latitudes trees may not produce as much biomass and consequently litter, even when the decomposition rate is restricted by the lower temperatures compared with low latitude sites.

The mean C stock in global temperate biomes is approximately 100 t C ha^{-1} (Lal 2005), but the mean appears to be somewhat higher in forests with mean stocks of 130 t C ha^{-1} reported for global mixed cool temperate forest soils using 56 samples (Adams 2004) and a median C pool in European Norway spruce forests estimated as 140 t ha^{-1} (de Vries et al. 2003). In general, the values reported in the present work are within the ranges of values found in the literature for older sites such as the 47-year-old stand (D47). The stocks for the first 20 years in the sites assessed were very variable (Figure 1). This may have been due to site preparation associated with afforestation which disturbed the soil C content by exposing lower soil layers to mixing with upper soil layers. However, stock quantities are within the ranges reported for other forests. In NE England 140 t C ha^{-1} were reported in a 40-year-old stand of Sitka spruce and 250 t C ha^{-1} in a 30-year-old reforested stand (Zerva et al. 2005). A Norway spruce plantation on glacial clay soils had 209 t C ha^{-1} in sites aged 55–60 years (Berg et al. 2001) and a greater stock was found in a mixed broadleaf stand in cool temperate Japan with a mean of 318.3 t C ha^{-1} in the mineral soil (Jia and Akiyama 2005).

However, in terms of C sequestration it would be desirable that a large proportion of the soil C would be held in the stable fractions of the SOM. This is represented in this study by the heavy fraction. The percentage of C held in the heavy fraction (84%) at the D47 site is similar to, but at the lower end, of the values reported in the literature. For example, 80.9% of the C was found to be in the heavy fraction in a study of 46 to 72-year-old forests on loam-dominated soils at seven sites in Washington and Oregon (natural range of Sitka spruce) (Swanston et al. 2002). However, Gregorich et al. (1994) found the heavy fraction to represent up to 99.1% of the soil C in clay loam soils in forests dominated by *Acer* spp. in Ontario, Canada. But the stock (140.64 t C ha^{-1} in the heavy fraction) was comparable to that found at the D47 site where the heavy fraction was 153.457 t C ha^{-1} (Figure 3).

Similarly, for a tallgrass prairie in Kansas and an abandoned pasture in Costa

Rica much greater proportions of the soil C were in the heavy fraction, 99.53 and 99.75% (Strickland and Sollins 1987) in comparison with the grassland site in this study where on 73% was contained in the heavy fraction. However, in this instance the G0 soil had a much higher stock of stable C (76.18 t C ha^{-1}) (Figure 3).

Thus the C dynamics in the soils of this study appear to be different than in other circumstances. The size of the soil organic matter (SOM) pool represents a balance between the organic matter input as litter and the rate of decomposition. Litterfall rates, together with the rates of decomposition will determine the size of the C litter pools and the amount of litterfall is positively correlated with NPP (Vilà et al. 2004), while the rate of decomposition is determined largely by climate, the chemical quality of the litter input and the decomposer organisms present in the system.

The amounts of litterfall at the sites are similar to those reported in the literature, both for monthly litterfall and peak patterns between months and generally between species. The annual litterfall was closely related to changes in leaf area index and net primary production (NPP) over the chronosequence (Tobin et al. 2007). The total inputs of 4.43, 2.02 and 1.93 t C ha^{-1} yr^{-1} in 34-, 39- and 47-year-old stands respectively reported in Carey and Farrell (1978) are also similar to the amounts measured in the D30 and C45 sites, which were 3.7 and 2.8 t C ha^{-1} yr^{-1}, respectively (Figure 5). Sitka spruce stands aged 25–30 across Scotland and Northern England had a lower litterfall of 1.6 t C ha^{-1} yr^{-1} (assuming C was 50%). An afforested site in Thuringia, Germany of Norway spruce had a similar yearly litter input for 30- and 57-year-old stands, 2.5 and 3.2 t C ha^{-1} yr^{-1}, respectively (Thuille and Schulze 2006). Sitka spruce on 30 to 34-year-old stands with similar precipitation and temperature in Denmark had an average input of 1.76 t C ha^{-1} yr^{-1} for five years 1989–1994 (Pedersen and Bille-Hansen 1999). However, this was on very sandy soil (89.2% sand).

In addition, the amount of standing litter at the mature site D47 (Figure 2) appeared to be very similar to values reported for other forests. Smith and Heath (2002) reported a mean value for forest floor litter of 33 t C ha^{-1} with a minimum of 4.6 and a maximum of 68.1 t C ha^{-1} for a mature spruce, fir (*Abies* spp.), hemlock (*Tsuga* spp.) forest type in north-eastern United States. This mirrors the findings of D47 with a mean of 21 (and a minimum of 15 and maximum of 39) t C ha^{-1}. The forest floor C stocks of a boreal pine forest chronosequence in western Canada were 16 t C ha^{-1} for a 30-year-old stand and 14 t C ha^{-1} for a 35-year-old stand, which are very similar to D30 (Figure 2) and ranged from 12 to 22 t C ha^{-1} for a 50-year-old stand, comparable again to D47 (Figure 2) (Nalder and Wein 2005).

In three 47 to 51-year-old stands of Norway spruce in Denmark, forest floor values were 13.14, 17.01 and 47.87 t C ha^{-1} on very sandy soils, indicating great within-site variability (Vesterdal et al. 1995). In another study three 33- to 34-year-old sites stands of Sitka spruce in Denmark had 7.21, 20.69 and 16.56 t C ha^{-1} in the standing litter on the forest floor (Vesterdal et al. 1998). This was comparable to the D30 site. In general, reports from Sitka spruce stands were similar to the results shown in Figure 2, but trends within particular sites varied slightly. It is therefore most likely that the decomposition process is the key factor leading to the differences in the proportions of stable SOM.

The mean C and N concentrations in the Dooary forest litter (Table 1) were 47.5% C and 1.20% N, which are comparable with the 48.4% C and 1.27% N reported by Carey and Farrell (1978). Pedersen and Bille-Hansen (1999) reported comparable mean N% in litterfall of 1.34% in Sitka spruce stands over a 5-year period (35-years-old). Miller et al. (1996) reported much lower N levels (0.69–1.07%) for Sitka spruce litter from stands situated across Scotland and Northern England in an age group of 25–30 years. There the percentages were weighted means to correct for the seasonality in N%, where levels decrease in the autumn and winter months, which may be a reason for the large discrepancy. The N% in needle litter was also reported to be 1.34% for green needle litter in Berg et al. (1993). Sitka spruce stands in Danish 33 to 34-year-old stands on sandy soils had 40.6, 41.9 and 46.2% C in the litter and 1.48, 1.65 and 2% N (Vesterdal 1998).

Mean lignin content was 41.2% for the forested sites of the chronosequence (Table 1). This is at the medium range of the spectrum of values reported in the literature. The lignin content of spruce litter in England was 48.5% (Rowland and Roberts 1994), which is one of the higher values. Rutigliano et al. (1996) reported lignin values of 40.47% lignin in fir in Italy. However, Norway spruce litter in southern Sweden ranged from 35%–36% (Lundmark-Thelin and Johansson, 1997, Berg 2000). *Pinus sylvestris* needles from SW England contained lignin values of between 20 and 32% (Sanger et al. 1996). Again Berg et al. (1993) reported lower values between 23.1–28.8% for Scots pine in East central Sweden.

This higher lignin content indicates greater C sequestration potential for this litter due to the inherent recalcitrance of lignin. This may also be a reason for the higher N% levels as the N is lignin associated and not as readily available to decomposers. Therefore, the SOM content at these sites is greater than might be expected. Further studies of C sequestration potential at other Irish forest stands of different species would require specific litter input data.

Soil microbial biomass affects the rate of decomposition. In the organic horizon of the grassland (G0), the soil microbial biomass was 4,991 μg C g^{-1} dry soil (Figure 6) which is higher than many of the values reported in literature. Four pastures in New Zealand had values which ranged from 1,125–1,724 μg C g^{-1} dry soil in the 0–10 cm horizon but was 479–575 μg C g^{-1} dry soil at a depth of 10–20 cm (Sparling 1992). The higher values were associated with the clay-dominated soils as opposed to the silt/loam soils. The soils in this study had a high clay content and this could explain the high microbial biomass content.

However, other studies have reported higher values on upland soils. Williams et al. (2000) reported 2,900 μg C g^{-1} dry soil for unimproved upland grassland and 1,600 μg C g^{-1} dry soil for an improved upland grassland in Scotland. These values are closer to those reported in this study where the chronosequence mean elevation was ca. 260 m. However, the values reported in Figure 6 are higher than the 847 μg C g^{-1} dry soil for a grazed site and 1,035 μg C g^{-1} dry soil for a managed fertilised grassland from Wales (Bardgett and Leemans 1995). The microbial biomass reported at Rothamsted Highfield Permanent Grassland Experiment was 948 μg C g^{-1} dry soil (Wu et al. 1995). That site also received an annual application of N fertilizer, however the sites in the current study had had little intensive management and it is highly unlikely that any fertiliser was added.

Bardgett and Shine (1999) found that increased diversity in plant litter increased the microbial biomass content in temperate grasslands. In a microcosm experiment the microbial biomass was 743 µg C g^{-1} dry soil for two species litter and 1,628 µg C g^{-1} dry soil for six species litter, indicating a possibility of greater species diversity in grasslands being indicative of lower management intensity and lack of fertilisation (Rodwell 1992, Smith, 1994). The G0 site in this study was on marginal land with minimal management and contained a variety of grass and rush species. Therefore, plant diversity could also have contributed to the large microbial biomass.

The soil microbial biomass of mature spruce forest (acidic type) in Taiwan ranged from 308 µg C g^{-1} in the subsoil (21–40cm) to 870 µg C g^{-1} in the topsoil (0–20cm), the organic layer contained 216–653 µg C g^{-1} dry soil (Yang et al., 2003). The 870 µg C g^{-1} for a dry soil is comparable to the organic horizon of the C45 site (705 µg C g^{-1} dry soil). The subsoil value of 308 µg C g^{-1} dry soil reflects the mineral horizon value in the site C45 (244 µg C g^{-1} dry soil), also indicating microbial populations decrease with increasing soil depth.

This reduction through the profile was also reported by Sparling et al. (1992) where the 0–10 cm depth had almost double the microbial biomass of the 10–20 cm depth sampled. The seasonal variation in microbial biomass could also be a factor; all forest samples were taken in the winter/spring time. Yang et al. (2003) found differences of up to a third in microbial biomass content when sampling at different times of the year. Bardgett et al. (1997) found grassland microbial biomass levels increasing by up to a half in the summer in comparison to the other three seasons. The grassland cores in this study were taken during the summer.

Mature Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) forest on volcanic soils in Washington had microbial biomass of 1,700 µg C g^{-1} dry soil, double the amount found at C45 (organic horizon) in Figure 2.5. Mature (90 and 115-year-old) Norway spruce in Lower Saxony, Germany had considerably higher values than reported here in the organic horizon: 2,651and 4,374 µg C g^{-1} dry soil versus 705 µg C g^{-1} dry soil at C45 (Figure 2.5). The mineral horizon values are more comparable, 224 µg C g^{-1} dry soil in site C45 (Figure 5) compared to 209 and 119 µg C g^{-1} dry soil in the study in Germany (Borken et al., 2002). These differing microbial biomass values in this study compared to other studies appears to be the key as to why there are generally higher SOM values in the forest soil in Ireland.

The microbial biomass total of 362.8 g C m^{-2} for the G0 site was also on the higher end of the scale for unimproved grassland sites (Figure 7 B). Soil microbial biomass increases as soil fertility decreases moving from improved to unimproved grasslands (Grayston et al. 2001). Ten unimproved grassland sites in Scotland had a microbial biomass mean of 89.4 g C m^{-2} (Grayston et al. 2004). However, it should be noted that these cores were taken to a depth of only 5 cm. Bardgett et al. (1997) showed the microbial biomass was positively correlated with SOM content across a range of upland grassland types, and with other studies of a wide range of managed and natural ecosystems (Wardle 1992, Zak et al. 1994).

One possible explanation for the higher grassland values of C content could have been that soil was sampled to a lower depth in this study. The addition of more soil lower in the profile would lead to increasing the microbial biomass content on an area basis. Bardgett et al. (1997) reported reductions in microbial biomass down through the soil profile in grasslands. There the cores were taken to 15 cm depth, whereas the soil core used in this study was 30 cm in length.

In summary, the grassland values are on the higher end of the scale of microbial biomass C and this may be due to a combination of higher elevation, lack of management, increased diversity, increased clay content in the soil and the sampling date being in the summer season. The forest values were difficult to compare to other studies due to a paucity of studies in Sitka spruce forests in Ireland. In some cases the values were similar in regenerating sites and samples taken in the winter. In other comparisons the forest sites were different to other sites and species but never by a large magnitude. In all cases the soil microbial C decreased down through the soil profile. In this instance the soil microbial C appears crucial in explaining the large pool of SOM accumulated over the chronosequnce. With the lower soil microbial biomass in the forests it could be hypothesised that the recalcitrant parts of the litter with higher lignin content is unavailable to these communities. The result was that the soil C increased over the timeframe of the chronosequence.

Conclusions

The results of this study supports the view that land-use change from marginal grassland to Sitka spruce forest can lead to significant C sequestration over the lifetime of the forest. This C increase in national forest stocks offers huge potential for the mitigation of GHGs, especially as much of the afforestation in Ireland will be classified as Kyoto forest. These data should allow more accurate modelling of the most common Irish forest ecosystem and, coupled with the microbial biomass data and soil fractionation data reported here, allow reporting to the UNFCCC at Tier 3 level.

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The Forests of Atlantic Europe

This is the second 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 forest grazing in Galicia, in North-West Spain and in south-central Portugal.

Sheep grazing in a beech forest in Northern Spain.

Forest grazing in Portugal and Spain

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Abstract

Forest grazing, one of the oldest examples of multifunctional forest management has been adapted to plantation forests in Galicia, in north-west Spain, with the aim of increasing profitability while decreasing the risk of fire. The principal plantation species in Galicia, maritime pine (*Pinus pinaster* D. Don) and *Eucalyptus globulus* Labill. can be grown at wide spacing and thus lend themselves to grass production systems, particularly early in the rotation. However, *Pinus radiata* (D. Don) although a minor species in Galicia, is the favoured species for intensively managed silvopastoral systems.

The wood-pastures, treed grasslands or heath-lands of central and southern Portugal and Spain represent the so-called European savannah known as montado, is well-suited to the traditional agroforestry practised in the region. Montado, a mixture of woodlands and scrub, is widely practised, principally in conjunction with cork oak production. The inter-tree spacing is used most commonly for pasture, but also for arable cropping. As in Galicia, management must take account of the ever-present risk of fire.

While neither of the systems described have a direct application in Ireland, they provide us with different perspectives on multiple-use and open to us the prospect of new, imaginative approaches to the multifunctional use of plantation forests.

Keywords: *Silvopastoralism, multifunctionality, montado, wood-pasture.*

Background

Forest grazing is one of the oldest examples of the multifunctional use of forests. The practice of grazing domestic animals, cattle, horses, goats, sheep and pigs in forests dates back many centuries. It is essentially, an agroforestry practice and covers a range of broadly synonymous terms, such as "pasture-woodland" and "silvopastoralism". Historically, it has been widely practiced in Atlantic Europe and this is still the case today.

The earliest recorded examples of silvopastoralism relate to woodland or forests of natural or semi-natural origin. However, this does not mean that these practices were entirely unmanaged. In many parts of Europe, pork, mainly as bacon, was an essential component of the diet in the Middle Ages. For a large part of the year, pannage, running pigs in the forest, was practised. In Britain, it can still be seen, on a small scale in the New Forest in Hampshire. The forest provided acorns, beech mast, chestnuts, or fruits such as apples, pears or cherries. Pannage was highly regulated; records of regulation go back as far as the sixth or seventh century (Vera 2000).

The development of scientific forest management and the narrow focus on the plantation forest as a "wood factory" in the early 19th century ran contrary to the

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concept of multiple use (Farrell et al. 2000). The forest was to be managed for the single purpose of timber production. Other management functions, of which animal production was one, were not permitted to deflect from this single-minded objective. The development of an active interest in silvopastoralism in plantation forests in recent decades, while it represents the modern view of the forest as an ecosystem providing a range of goods and services to society, is in fact a reversion to a much older and long-lived view of the role of the forest.

This article focuses on two aspects of managed grazing in planted forests in Spain and Portugal, grazing in plantation forests, mainly pine, in Galicia, in north-west Spain and the montado, the traditional agroforestry system of Portugal which is dominated by two oak species.

Grazing animals in forest ecosystems

Large herbivores are a natural component of forest ecosystems. Their significant, often complex impact on forest canopy composition has been widely reported (Mitchell and Kirby 1990, Palmer et al. 2004, Evans et al. 2006). The present composition, structure and grazing regimes of current forests are to some extent the legacy of past management, of both domestic animals and the impact of forest management on wild herbivore populations (Bradshaw and Edenius 1998). The current management of silvopastoral systems, even in plantation forests, will have to take account of the wild animal population and may have to, depending upon the scale of operation, devise strategies for its management, which may include culling, as appropriate.

Ruminants have been classified as grazers or browsers, or, sometimes according to more complex schemes (Gordon 2003). Grazers and browsers often coexist in forest ecosystems. Browsers, herbivores which feed on leaves, soft shoots or fruits, actively select woody plants. Herb species form the major part of the diet of grazers, but they also eat woody plants and are apparently less discriminating than browsers in their choice of woody species (Hester et al. 2000). Cattle (*Bos primigenius*) are grazers, predominantly grass and forb feeders. They can also exert a significant trampling effect; the ground pressure exerted by their hooves is almost three times that of sheep (*Ovis aries*). Even low-intensity grazing can reduce infiltration and increase susceptibility to erosion (Pietola et al. 2005). Sheep and goats (*Capra hircus*) are sometimes referred to as intermediate grazers, with sheep predominantly acting as grazers. Sheep are highly selective herbaceous feeders, but they will browse when availability of herbage is limited. Goats are predominantly browsers; they can be very destructive to saplings through bark stripping.

Managed grazing in Galicia, north-west Spain

The total area of Galicia, in northwest Spain, is just under 3 million ha, 35% of the area of the island of Ireland. It is the most important forest region in Spain. Forests account for 69% of the area of Galicia (Fuentes-Santos et al. 2013) and annual production, at close to 7 million m^3 $year^{-1}$, represents about 50% of Spanish timber production (Fearmaga 2011).

Several factors favour silvopastoralism in plantation forests in Galicia. Firstly,

Figure 1: *Uncontrolled cattle grazing, Xesta, Pontevedra Province, Galicia.*

there is a strong tradition of grazing scrubland and woodland in Galicia. Indeed, the word "monte", which is used to describe woodland in Galician, encompasses also riparian communities and natural grasslands. Typically, these areas were grazed during the dry summer season. Traditionally, scrubland was highly valued. Not only was it used for grazing, but it was a source of firewood, charcoal and litter. Multiple land use, promoted by the monastic orders in the Middle Ages, continued into the twentieth century (Villares (1998) in Calvo-Iglesias (2006)).

Wildfire

Wildfire is a major problem in Galicia. Between 1961 and 2011, a total of 245,593 wildfires, affecting an area of almost 1.8 million ha were recorded (Fuentes-Santos et al. 2013). A very high proportion of these fires were started deliberately. According to the same authors, 87% of the fires in a study area in Lugo province, in eastern Galicia, were attributed to arson.

The primary function of plantation forests in Galicia, in northwest Spain, is wood production, for pulp, board and timber. However, the risk of forest fire and low wood prices significantly reduce the financial viability of forest enterprises. Managed grazing of plantation forests is promoted in Galicia as a means of reducing the incidence of wildfires, or of at least mitigating their impact, by reducing the amount of combustible material in the forest. However, it also has a financial benefit as the early return from grazing can enhance the profitability of the plantation.

The practice of poorly managed or unmanaged grazing of forest lands persists and can often increase the risk of forest fire. Fires, employed by shepherds to promote the growth of more palatable grass species, often get out of control. Nevertheless, grazing, even poorly managed, can lessen the incidence of fire through reducing the fuel load of the understory vegetation. The value of grazing as a means of scrub control, thus reducing the serious risk of fire, is widely recognised in Galicia, although its efficacy has not been conclusively confirmed in the literature (Pasalodos-Tato et al. 2009). Nevertheless, there is a clear perception in scientific studies that when land is abandoned, the fire risk is increased. Ironically, although most of the fires are started deliberately, the risk of serious damage increases as the rural population declines.

The catastrophic wildfires of recent years, particularly in 2006, have increased interest in the use of grazing as a fire protection measure. Proposals from the forest administration and from the owners of communal forests include, improbably, the use of sheep to create firebreaks. The Consellería do Medio Rural (Xunta de Galicia) has promoted many projects for the development of managed silvopastoralism on marginal sites, providing funding for fencing, road improvement, the provision of drinking places for animals, as well as for shrub clearance and soil improvement. A feature of this programme is that plantation forest establishment and pasture development are seen as inextricably linked.

Grazers and browsers

Cattle form the most typical animal component of silvopastoral systems in the Atlantic regions of Europe, although horses, goats and pigs are also used. Farmers have traditionally used the Galician Red cattle (*Rubia gallega*) for forest grazing, although it may not always be the most suitable breed. Cattle are particularly useful for trampling bracken, but on the heather-dominated mountains of eastern Galicia, they are of little use. Goats are very effective in vegetation control. They are also commercially interesting, as kid meat is very valuable. Horses are also good for gorse control. Goats may adversely affect regeneration and damage seedlings, but this can be minimised with appropriate stocking levels. Pigs are used in oak and chestnut stands, a practice of long standing, although this is uncommon in Galicia.

Plantation species

The principal plantation species used in Galicia are maritime pine (*Pinus pinaster* Aiton), covering 28% of the forest area, and *Eucalyptus globulus*, 12%. Monterey pine (*Pinus radiata* D. Don), although it comprises only about 4% of the total forest area, is the favoured species for intensively managed silvopastoral systems although cattle are grazed in eucalypt plantations also. These species can be grown at wide spacing and do not form dense canopies. While the results of many studies have shown that grasses compete with trees, presumably for water, others suggest that establishment of grasses results in improved tree growth, because grasses compete less aggressively with trees than native shrub species (Pasalodos-Tato et al. 2009). Following site preparation, trees are planted and grass sown at the same time. Tree tubes are often used to protect seedlings during the establishment phase. Sheep, the principal livestock species used in these systems, can graze the pastures within the first year, bringing an immediate financial return. Pasture production in these systems is highly dependent on stand development and canopy cover. In a study on optimal management in a Monterey pine silvopastoral system in Galicia, Pasalodos-Tato et al. (2009) modelled the dependence of pasture production on stand basal area and site index. This was a high-production Monterey pine site with site-indices in excess of 25 m at 20 years. Profitability was maximised with initial stand densities of 1,500 stems ha^{-1}. In highly productive pastures, profitability was maximised at lower stand densities. When fire risk was included in the analysis, silvopastoral systems were always more profitable than plantations devoted solely to timber production. Where the fire risk is significant, lower planting densities are favoured, because under these circumstances, income from grazing dominates, reducing the potential fire loss. In highly productive systems, grazing generates significant returns early in the life of the plantation, so financial rotation is optimised at shorter rotations, allowing the early renewal of the productive pasture period. For financial viability, this type of silvopastoral system requires a forest of at least 200–300 ha (Pasalodos-Tato et al. 2009).

In the study described above, grazing was carried out entirely in the plantations. However, in other cases, a proportion of the site is set aside for grass production only. The cattle are free to graze in this area and in the forest. Typically, they prefer the open areas, but use the forest for shelter in bad weather. A 300 ha block of

Figure 2: *Communal eucalypt/pine plantation, Ponte Caldelas, Pontevedra Province, Galicia. Note managed grassland, right centre, within forest boundary.*

pine/eucalypt plantation, typically in communal ownership, might have 10% of the area set aside for grass only.

Benefits of silvopastoral systems

It is suggested that a well-managed silvopastoral system might be mutually beneficial to both the animals and the forest. Not only can the trees offer an improved microclimate for the animals, the trees may also benefit, from the fertilising effect of the animals, their influence on soil disturbance, the control of competing vegetation and possible pest control. Wild boar may contribute to the development of a favourable seedbed for regeneration through soil disturbance, but they can be detrimental to sapling establishment (Kuiters 1998). The essential element of good management is the appropriate regulation of animal numbers and following best practice regarding times of the year when the animals can be safely allowed into the forest.

Montado – a traditional agroforestry system of Portugal

The wood-pastures, treed grasslands or heathlands of central and southern Portugal and Spain represent the commonly-named European savannah (Rackham 1998). This type of vegetation is much more suitable for grazing in this region than closed forest, which carries limited forage for most animal species. The highly artificial ecosystems of the Portuguese montado and the dehesa of central and southern Spain, prime examples of multifunctional use, come under the heading of cultural savannah.

Montado is an extensive multifunctional land-use system dating from the 18th century. Montado covers at least 25% of Portugal and, under the name "dehesa", a proportionately smaller, but large area of Spain. Although montados are found under a range of climates from maritime to continental, it finds its best expression in the Mediterranean climate of Alentejo, in south-central Portugal. It is included here because it is such an excellent example of multifunctional land use.

The montado is an agro-forestry pastoral ecosystem with typically, a tree density of 60–100 stems per ha. The main tree species are cork oak (*Quercus suber* L.) and holm oak (*Q. rotundifolia* Lam.).The management goals vary, but include cork, acorns (particularly of holm oak), pasture, arable crops and hunting. Traditionally, cereals were the principal inter-tree crop, but grassland is more common nowadays. Pig and cattle production are of major importance. Crops include clover, wheat, barley and oats, often grown in rotation with a fallow period when no crop is grown. While the principal value of cork oak lies in the cork, acorns represent the major commercial product of holm oak. Other products of the montado include mushrooms, honey and firewood.

Montado is a very intensive production system. Cork trees are planted, or established by direct seeding. They are pruned to give clean stems. They cannot be felled without permission of the Forest Service. Pine is sometimes grown with the cork oak, but it is usually removed at about 20 years. Cork production begins when the trees are about 20 cm DBH and thereafter at intervals of about nine years, or longer, depending on site quality. The first extraction, known as "male or virgin"

Figure 3: *Montado, springtime, Gambia, Setúbal, Portugal. Note the numbers on the trees indicating their place in the cork production cycle.*

cork, is not used for stoppers. The second and third extractions, "gentle" cork, have higher value and are suitable for stoppers. Harvesting of the cork is carried out in the summertime, when it can be done without damage to the trees. Care must be taken in allowing animals access to cork oak stands as the trees from which cork has been harvested are vulnerable to damage. They are usually excluded for about four months following extraction.

Grazing animals in montados include cattle or sheep, rarely black pigs and occasionally fighting bulls; sometimes these lands are not used for grazing at all. Cattle grazing is not ideal in cork oak stands, although it may be permitted for a limited time. Cattle can cause significant damage, especially to young trees and must be carefully managed. Sheep, on the other hand, can be left to graze all-year round. The critical months for forage production are December and January. Sheep are often provided with supplemental fodder, silage etc., during this period.

Shrub growth, predominantly of the genus *Cistus*, is often vigorous, providing cover for game (hunting is a popular activity on these lands) and fodder for cattle. However, shrubs greatly increase the risk of fire and are also a source of competition for water and nutrients. Artificial control is usually required. Mechanical cleaning is considered harmful so manual cleaning is preferred. Controlled goat grazing has been suggested, but this is rather controversial, because of the potential for damage caused by the goats.

Biodiversity varies considerably in the montado. This is not surprising given

Figure 4: *Montado, sheep grazing, Gambia, Setúbal, Portugal.*

their wide geographical distribution, with climate varying from maritime to continental. Bird diversity is particularly high. The relative importance of natural and human influences on bird populations was studied by Pereira and da Fonseca (2003). They concluded that despite the strong human intervention in the montado, natural environmental influences remain significant. They also point to the contribution of ecological corridors to the maintenance of biodiversity.

Acorns are a major product of holm oak, in comparison with cork oak stands. Acorn production is irregular, but when good, it is very important for cattle, sheep and even deer. Pollen levels during the flowering season and water availability during the period April to September have been reported as major determinants of acorn production (García-Mozo et al. 2012).

Conclusions

Forest grazing practices in Galicia and Portugal have their roots in traditions which extend back many hundreds of years. In Galicia, traditional forest grazing practices are being adapted to plantation forests to develop intensive, profit-oriented management systems. By successively combining wood and animal production, managers can increase productivity while simultaneously reducing the ever-present risk of fire.

In our relatively limited forest tradition in Ireland, grazing animals are often seen as a threat to plantation forests. While it would be foolish to ignore the potential damage animals can cause to young forests, it is worth considering practices in Galicia, to see if there is anything we can learn from them. Of course, one must take into account the structural differences between our plantation forests and those of Galicia. Most of the species used in Irish plantations, particularly Sitka spruce (*Picea sitchensis* (Bong.) Carr.), cast deep shade on the forest floor, suppressing virtually all ground vegetation, particularly in the pre-thinning stage. The eucalypts and pines used in Galicia have light open crowns. They are also amenable to wide initial spacing and these two factors allow high light levels on the forest floor and consequently vigorous grass and shrub growth. The fire control benefit of grazing is not of great interest in Ireland, but the prospect of an early financial return from a plantation would clearly be attractive. While forest grazing practices in Galicia may have no direct application here, it is worth recognising that the apparent conflict between the forest and grazing animals is fundamentally a tension between different human objectives.

Agroforestry systems, such as the montado, open our eyes to another, very different aspect of the multiple-use of forests. Cork, crop and animal production systems have been managed sustainably in this ancient system for many hundreds of years. Perhaps it is worth considering how the tensions which exist in Ireland between grazing and forest establishment can be minimised, or even, as in the examples cited in Spain and Portugal, converted to a mutual economic and ecological advantage.

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Forest Perspectives

John F. Kennedy Arboretum a national botanical treasure

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Keywords: *Arboretum, collections, international research, amenity.*

Introduction

Following the death of John Fitzgerald Kennedy, President of the United States of America, on 22nd November 1963, a number of Irish-American societies wished to establish a memorial forest as a living tribute to him in Ireland. The Irish government suggested this take the form of a national arboretum. The Irish-Americans agreed readily and raised $145,000, which was equivalent to about the value of the arboretum land at that time. The Irish government undertook to develop and maintain the arboretum, which was to be located in Co. Wexford. The JFK Arboretum was opened formally by President de Valera on 29th May 1968.

Arboreta or collections of trees and shrubs were first planted when it was realized that timber from native woods was not inexhaustible. In Ireland the planting of groups of exotics started at the end of the 17th century, with the coming of political security for landlords. These collections grew with the introduction of more exotic species, especially since the beginning of the 19th century. While many of these large plant collections had specimens of great botanical interest, in general they were not comprehensive nor arranged scientifically. This was also a period of economic hardship, so there was uncertainty as to the long-term commitment of owners to the long-term protection of valuable plant collections. A national institution appeared to offer the best safeguard towards this continuity. The National Botanic Gardens, founded in 1790 by the Royal Dublin Society, was limited in its ability to display a comprehensive collection of trees and shrubs, mainly due to its size of 19.5 ha. An area of 80 ha was considered necessary for this purpose and to allow for the future expansion of collections. For these reasons, the need for a national arboretum had long been recognised. One of the main functions of the arboretum has been as a testing ground for newly discovered species, cultivars and hybrids. Where space permits, plots of species with an afforestation potential were established and demonstration provenance trials containing forest tree species of value to Irish forestry were also included. Properly arranged and displayed, the collections should be a source of knowledge for students, gardeners and planners over many generations.

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Figure 1: *The long vista – framed by shelter belts, it leads northwards to the visitor centre, with Slievecoiltia in the distance.*

A planning committee was established between the Forestry Division and the National Botanic Gardens to plan the content and layout of the Arboretum and the Office of Public Works, which had the responsibility for providing the buildings, roads and services. Initially, committee members visited arboreta and botanic gardens in the U.S., U.K. and continental Europe, to study methods of arranging the collections, recording, etc.

Plant arrangements in Avondale Forest Park were also examined for this reason. Instead of the separate arboretum and pinetum, in John F. Kennedy (JFK) the Plant Collection was planned in two interwoven botanical circuits, one of broadleaves and the other of conifers, which minimised the visual impact of bare-foliaged broadleaves in winter. The Long Vista in JFK (Figure 1), modelled on the Great Ride, is 1 km long and 30 m wide, aligned north-south and bisects the holly (*Ilex aquifolium* L.), horse chestnut (*Aesculus hippocastanum* L.), maple (*Acer* spp.) and members of the rose or Rosaceae family collections.

The plots in Avondale were generally 0.4 ha in area, about 10 times as long as wide, tending towards a single line of trees as the final crop. In JFK, the main forest plots were also 0.4 ha in area, but square, to give a final crop with timber measurements more akin to what might be expected in a real forest situation. "Nurse trees" were not used in JFK and tender species suffered damage from exposure during the early years, but recovered quickly after this. Avondale provided seed for 14 plots in JFK Arboretum. The best examples are Macedonian pine (*Pinus peuce* Griseb.), Serbian spruce (*Picea omorika* (Pancic) Purkyne) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), in addition to other unusual species.

The site

The JFK Arboretum is located in the southeast corner of Ireland, 12 km south of New Ross. It covers 252 ha and rises from 36 m at its southern boundary to 271 m at the summit of Slievecoiltia ("Mountain of Woods"), a prominent hill overlooking the Kennedy ancestral home at Dunganstown.

The main part of the Arboretum had been a large working farm of 158 ha, transferred from the Land Commission in 1964. The two monkey puzzles *(Araucaria araucana* (Mol.) K. Koch*)* at the visitor centre, planted in 1920, were the only exotic trees growing there. A further 28 ha farm, rising to 190 m, plus an 8 ha forestry plantation were acquired in 1965. This site was considered suitable for growing a large range of tree and shrub species. A soil survey, carried out by An Foras Talúntais in 1968, showed the predominant soil to be a deep brown earth over Ordovician slate and shale, with an average pH of 5.7. In 1978, the 58 ha summit of Slievecoiltia was added, to give a total area of 252 ha.

The climate of the arboretum is typical of the south-eastern coastal region. Temperatures range from a mean January minimum temperature of 2.7ºC (absolute minimum −8.4ºC in January 1979) to a mean July maximum temperature of 19.4ºC (absolute maximum 29.4ºC), for the period 1968 – 1998. The mean annual rainfall received is about 1004 mm. Rosslare Strand in this region, receives about 1,600 hours of sunshine per year, more than the rest of Ireland. The main limiting factor for establishment was exposure, and shelterbelts were planted initially, to protect young specimens. The species planted for shelter were Japanese larch *(Larix kaempferi* (Lamb.) Carr.*)*, giant fir *(Abies grandis* (Dougl. ex D. Don) Lindl.*)*, Lawson cypress *(Chamaecyparis lawsoniana* (A. Murr.) Parl.*)*, western hemlock, common beech *(Fagus sylvatica* L.*)* and red oak *(Quercus rubra* L.*)*, to give extra autumn colour.

The JFK Arboretum has five main objectives, as follow:

- Demonstration – To display a comprehensive collection of trees and shrubs and a series of forest plots, properly arranged and labelled.
- Education – To be a source of knowledge of trees and shrubs for students, planners and the general public and to give guided tours.
- Research – To record the performance of a wide range of trees and shrubs in open and forest conditions. To cooperate with other organisations in conducting studies of mutual interest.
- Conservation – To make provision for the inclusion of endangered species and cultivars in the collections and to establish pools of genetic material of these.
- Recreation – To provide a setting in which to enjoy leisure activities and stimulate an interest in woody plants.

The plant collection

The plant collection covers 125 ha and occupies the parkland of the lower southern slopes of Slievecoiltia to an elevation of 85 m. Initially, it had been planned to establish a horticultural college on 20 ha in the south west corner of the site, but this idea was abandoned in favour of Kildalton in Co. Kilkenny. This corner became the

Extension Area and contains part of the cypress family (Cupressaceae) with provenance display plots and an elm (*Ulmus* spp.) "adaptability" trial.

Approximately 4,500 species and cultivars of trees and shrubs are represented. In planning a comprehensive collection capable of growing in the Arboretum's climate, a final content of between 5,000 and 6,000 species was envisaged. The families are arranged by taxonomic classification, based on the system of Engler and Prantl[1].

There are some modifications, the main one being the planning of the conifers in a separate circuit, but interwoven at times with the broadleaves to improve the overall appearance of the collection.

Other modifications included the planting of certain genera to take advantage of a sheltered position, or moving collections to reduce the risk of disease, such as planting the *Ribes* collection downwind of the "five-needle pines" (*Pinus* spp.) to reduce the likelihood of an outbreak of the white pine blister rust (*Cronartium ribicola* J.C. Fisch.), Priority was given to species and natural varieties of wild origin, with interesting cultivars represented where space permits. Up to three specimens of each type were planted at a spacing sufficient to allow for full development of the crown, free from competition. Each plant is labelled and a record is kept of its growth over time. Growth assessments have been carried out periodically.

As the area is exposed to the prevailing south-west winds, any existing woodland is retained to perform the dual function of giving shelter and providing a setting for sylvan walks. Shelter belts of two rows of trees were established 40 m apart initially to protect young specimens. These are being removed as they become superfluous. Several vistas extend through the plant families and provide glimpses of the surrounding countryside.

For ease of plotting and indexing, a system of numbered grid-points was put in place, the markers consisting of sunken blocks of concrete set to the cardinal compass points, 61 m apart, and numbered consecutively. A set of large scale maps, at a scale of 1:240, is used in conjunction with this grid, and provides for the accurate planning of specimen positions.

The ericaceous garden (Figure 2) is part of the botanical circuit but deserves special mention. It was designed by the National Botanic Gardens in Dublin and covers nearly 5 ha. There are more than a 1,000 different species and varieties of this family growing there. The main species are rhododendrons and azaleas *(Rhododendron* spp.*)*, and heathers (*Calluna* and *Erica* spp.), with many other genera included. Initial mulching with peat provided the acid soil condition required by these species. Specimen trees have been planted throughout, to give some vertical scale, and provide a more natural setting, with protection from the wind. There is colour all year round, although the best time to view is late April, May and early June when the plants are in flower.

1 Engler and Prantl's (1887–1915) *Die Natürlichen Pflanzenfamilien* was one of the few detailed works to attempt the classification of the plant world since Linnaeus.

Figure 2: *A view across a bed of evergreen hybrid azaleas in the ericaceous garden. Note the anemometer sited in the bed.*

Other collections

- Climbing plants – A selection of climbing plants is growing on four stone and timber shelters.
- Hedges – Different hedges in the picnic area, serve the dual purpose of demonstration and the provision of shelter. A planted maze of 24 m diameter is nearby.
- Slow-growing conifers – A landscaped area contains a collection of 300 species and cultivars of slow-growing conifers (See Figure 3).
- Ground-cover – A collection of plants suitable for ground-cover is growing near the main woodland block.
- Waterside plants – There are examples of these plant types found by stream and pond sides for use in similar situations.
- Street trees – There are demonstrations of trees commonly used as street trees in an urban setting, including many poplar *(Populus* spp.*)* clones, both old and new.

Plant supply

Twenty-two countries, with which Ireland had diplomatic relations, each sent gifts of trees and shrubs representative of their country to the Arboretum. The main source of plants used in the Arboretum has been from reputable nurseries that could authenticate the source of their material. Plants, cuttings and seed are also received as gifts or by exchange from other arboreta or botanic gardens. The Arboretum has a

Figure 3: *The view southeast over beds of dwarf spruce and other slow-growing conifers to the wooden shelter. Part of the cherry (*Prunus *spp.) collection appears in the gap to the left.*

nursery, with propagation house, covering about 1 ha. In addition to propagation, plants are held here prior to planting out in the plant collection or forest plots.

Forest plots

The forest plots extend up the slope of Slievecoiltia to 190 m above sea level. They occupy 61 ha and in contrast to the Plant Collection, are arranged geographically. The vigorous tree species from Western North America protect the windward flank of this area. Those from eastern North America, South America, Australasia, and Asia stretch across the slope, while the hardier species from Europe are at the higher elevations. The area is divided into 0.4 ha squares, with rides of 2 m or 4 m between each plot. Plot sizes range from 0.4 to 0.1 ha; the exact size apportioned depended on planting stock availability and perceived hardiness of the species (i.e. smaller plots of lesser-known species were planted to determine how they might perform and eventually justify further planting in the arboretum). Where these squares are divided into smaller plots, it is important that there is sufficient area and number of trees to permit accurate estimation of tree growth responses at the stand level (e.g. volume), including the impact of thinning. Both evergreen and deciduous species were planted to give variety to the overall appearance, although where provenances of the more important species are included, they are kept together.

Material from the following locations is included in the collection:

- Western North America – 50 plots. These include three clones of ×*Cupresso-cyparis leylandii* (Dallim. and Jacks.) Dallim. The ×*Cupressocyparis leylandii* (Dallim. and Jacks.) Dallim. "Castlewellan" plot was used to demonstrate "line thinning" in 2003. There are five provenances of *Picea* *sitchensis* (Bong.) Carr and five of *Pinus contorta* Dougl. ex Loud., three of coastal (ssp. *contorta*) origin. The most vigorous plots here are *Abies grandis* (Dougl. ex D. Don) Lindl. and *Cupressus macrocarpa* Gord. *Alnus rubra* Bong., initially the most promising species, soon declined although it has rallied somewhat in later years.

- Eastern North America – 36 plots. The best plots contain *Pinus strobus* L. and *Quercus rubra* L.
- South America – six plots. There are three provenances of *Nothofagus procera* (Poepp. Endl.) Oerst. which were vigorous with good form. Currently there are only a handful of trees remaining in these plots. The *N. obliqua* (Mirbel) Blume trees had been in decline for a number of years and all have died in more recent years.
- Australia, New Zealand – 44 plots. These are mainly *Eucalyptus* species, the outstanding one being E. *nitens* Maiden. A plot of this species at over 200 m elevation on the eastern flank of Slievecoiltia, succumbed during the recent cold winters.
- Asia – 51 plots. The most vigorous plots here are *Cryptomeria japonica* (L.f.) D. Don, *Larix kaempferi* (Lamb.) Carr. and *Picea likiangensis* (Franch.) Pritz.
- Europe – 85 plots. This area includes five plots of mixtures of two species to reflect a recent trend in the national planting programme. The first plots were planted in 2001 to replace *Pinus nigra* ssp *nigra* J.F. Arnold, which was destroyed in the 1997 storm. The species used were *Pinus sylvestris* L. and *Quercus petraea* (Mattuschka) Lieblein. The best plots contain *Abies alba* Mill., *Alnus cordata* (Loisel) Desf., *Larix × marschlinsii* Coaz, *Picea abies* (L.) Karsten and *Pinus peuce* Griseb.

Table 1: *Synopsis of main forest tree plots.*

Genus Species	Common name	Provenance	Planting year	Productivity ($m^3 ha^{-1}$)
Western North America				
Abies grandis	Grand fir	West Cascades, Washington	1969	26.1
Abies procera	Noble fir	Randle, Washington	1966	19.3
× Cupresso cyparisleylandii	Leyland cypress	Haggerston No. 2	1967	20.3
Cupressus macrocarpa	Monterey cypress	Ballintombay, Rathdrum	1967	26.3
Picea sitchensis	Sitka spruce	Alberni, V. Is.	1966	21.8
Pinus contorta var contorta	Beach pine	Long Beach, Washington	1966	17.9
Sequoia sempervirens	Coastal redwood	California	1972	17.0
Thuja plicata	Western red cedar	Masset, Q.C. Is.	1967	20.0
Tsuga heterophylla	Western hemlock	Avondale Forest	1966	20.6

Table 1 (*continued*)

Genus Species	Common name	Provenance	Planting year	Productivity ($m^3 ha^{-1}$)
Eastern North America				
Pinus strobus	Eastern white pine	State of Michigan	1969	14.5
Quercus rubra	Northern red oak	Campine, Near Antwerp	1966	5.7
South America				
Nothofagus obliqua	Roble beech	B.F.C., England & Wales	1977	7.4
Nothofagus procera	Rauli beech	Malleco, Chile	1977	14.7
Australia and New Zealand				
Acacia dealbata	Silver wattle	Judds Ck, Tas.	1984	18.3
Eucalyptus nitens	Shining gum	Anembo S.F., N.S.W.	1982	31.0
Asia				
Cryptomeria japonica	Japanese cedar	(Eichenberg)	1972	18.7
Fagus orientalis	Oriental beech	North Caucasus	1967	10.6
Larix kaempferi	Japanese larch	Nagano, Japan	1967	13.2
Picea likiangensis	Likiang spruce	Avondale Forest	1967	12.9
Europe				
Abies alba	European silver fir	South Europe	1967	20.4
Alnus cordata	Italian alder	Salerno, Italy	1967	16.4
Larixx marschlinsii	Hybrid larch	State Seed Orchard, Denmark	1971	18.0
Picea abies	Norway spruce	Paneveglio, Italy	1967	16.9
Pinus peuce	Macedonian pine	Avondale Forest	1967	18.6

Slievecoiltia

The summit of Slievecoiltia covers 66 ha. The 8 ha forestry plantation covers the south east slopes of the mountain. Planted in 1961, it had been part of New Ross Forest. There is a demonstration of native woodland here. This is balanced by similar planting to the north west. Native woodland species have been planted to the north, while the natural hilltop vegetation is being left undisturbed. There is a road to the summit and a viewing point. On most days there are panoramic views over parts of six nearby counties, from Galtymore Mountain (920 m) 80 km to the west in Tipperary, to Croaghanmoira Mountain (665 m) 74 km to the north east in Wicklow.

Management

Planning meetings were held at regular intervals from 1964, either in Dublin or on site. After the Arboretum opened on 29th May 1968, the committee was restructured.

Meetings were attended by four or five representatives of the Forest Service, (headed by the Chief Inspector, in the seventies and Asst. Chief Inspector or Senior Inspector, in the 80s) and two representatives of the Dept. of Agriculture (Senior Inspector and Director, National Botanic Gardens). An advisory committee comprised mainly of university professors, was invited from time to time, to present their views on Arboretum development.

The last committee meeting was held in May 1987. The Arboretum remained within the Forest Service until 1989, when it was handed over to Coillte Teoranta for four years, before joining The Office of Public Works in 1993 under Historic Properties. Following the years with Dúchas, from 1997 until 2003, it returned to the OPW and has remained there until the present (2013).

Description of current situation in JFK arboretum

Demonstration

- Signage – The current range of arboretum signage includes public road, main gate, parking and buildings signs as well as title signs for each prominent collection along the internal road and Long Vista. It includes five maps at intervals around the circuit and two maps on Slievecoiltia. The use of more detailed signs is being considered.
- Labelling – This is a continuous process as labels are lost or stolen over time. The traditional engraved black plastic tag is being supplemented by an efficient portable system of black plastic tape affixed to a rigid plastic tag. There is an engraved black plastic label on the north and south sides of each forest plot.
- Operations – Techniques in cultivation and maintenance will continue to be demonstrated, e.g. mound planting in damp areas, best-practice pruning of specimens and the presentation of collections.

Education

- Trails – There are three self-guided trails and a self-guided nature trail, which is specifically aimed at school groups. A map and a guidebook are also provided.
- Guided tours – These are available on request for groups during the summer season, although the public is advised to make reservations in advance during the busy peak periods. Occasional open days are held in conjunction with National Tree Week, Heritage Week and National Tree Day. In addition to the usual guided walks or tree planting, there are often special displays.

Research

The whole arboretum may be considered a species trial. In the early years, height, diameter (single stemmed trees only) and crown spread of each specimen was measured every five years until the end of 1989. The growth of all trees in the forest plots was also recorded at five-year intervals until 1995. These are updated as plots are thinned. The figures include the heights of trees, and the volume of timber removed from each plot and that remaining in the plot.

The performance of a wide range of trees and shrubs will continue to be recorded as required and the adverse effects of climate, diseases or insects on them will be recorded, as will the results of subsequent remedial action. Plant records of a number of estates and gardens are held, including the lists for the collections of H.M. Fitzpatrick (1931 and 1932) and A.F. Mitchell and A.M.S. Hanan (1966 and 1968).

An international phenological garden is situated near the main buildings as part of a scheme to study the effect of climate on plants. This is one of five such gardens in Ireland and is part of a network of 89 across Europe. During the appropriate part of the season, daily observations are made of the first leaves, flowers, fruits, leaf colouring and leaf-fall. The results are sent to the Irish National Meteorological Service, the co-ordinating body for Ireland, which are in turn forwarded to the University of Berlin.

To the south west of the plant collection is a provenance display of major forest tree species on 8 ha, which demonstrates the extent of genetic variation within the natural distribution of each species. There are 80 provenances of Sitka spruce covering its entire range, from Alaska to California. Records have been kept of growth periods and morphology of open grown trees compared with those in plantations.

An elm adaptability test, part of an EU project on Dutch elm disease, is adjacent to the provenance display. Records were kept of height growth, and observations made of tree form, leaf colouring and incidence of disease. Many of these plots have succumbed to the disease at this stage.

Conducting studies of mutual interest with other organisations will continue. Examples in recent years include the supply of yew *(Taxus baccata* L.) cuttings to the Dept. of Pharmacology, TCD, for Taxol extraction; the supply of southern beech *(Nothofagus* spp.) cuttings to the New Zealand Forest Research Institute in a study of insect damage; and due to climate change the increased interest of the International Phenological Gardens group in information on the timing of key plant developmental stages. There also has been wide interest by COFORD, UCD Forestry and Coillte Research in the performance of the forest plots.

There is a meteorological station, where daily readings are made of air, ground and soil temperatures, rainfall, evaporation, sun duration and wind direction and run (in km). Returns are made to Met Eireann each month. A series of anemometers at selected locations around the arboretum has measured the build-up of shelter over the years. The coldest air temperature recorded, −8.4ºC on 2nd January 1979, damaged quite a few specimens including some *Eucalyptus*, *Acacia*, *Hebe* and other spp.

Conservation

Endangered species and cultivars will continue to be included in the plant collections. Propagation material has been provided to outside bodies where plant species were unavailable elsewhere. Plant material will continue to be provided to other institutions wishing to establish arboreta.

Wildlife conservation
The Arboretum is a haven for wildlife. In the early years, 82 bird species were observed and a Baseline Survey of Birds was carried out in 1994/95. Current figures for abundance are 65 bird, 17 mammal and 20 butterfly species. The red squirrel (*Sciurus vulgaris* L.*)* is doing well and any invading grey squirrels (*Sciurus carolinensis* Gmelin; which first appeared in 2006) are being trapped. A programme of wildlife conservation has been drawn up by a staff member with the appropriate training.

Recreation
As well as providing a place to enjoy leisure in beautiful surroundings, young families are well catered for. There is a play area for different age groups, a maze and picnic site beside the tearoom and shop (Figure 4). A miniature railway runs during afternoons in summer in the south-western corner of the arboretum and there is a nature trail, aimed at school groups. The lake (Figure 5), with its rudd (*Scardinius erythrophthalmus*), mallard duck (*Anas platyrhynchos*) and water hens (*Gallinula chloropus*), is the most popular area.

In recent years, there have been special events including orienteering, inter-schools running, scouting activities, displays by woodworkers, craftspeople, pipe bands and family orientated eco-trail.

Figure 4: *The picnic area, interspersed with different hedges and tables, leads to the tearoom. Older woodland forms a sheltering backdrop.*

Figure 5: *The lake is located in a corner at the JFK Arboretum, bordered by lawn and waterside plants, with shelter belts and mature Scots pine in the background.*

Visitor centre

The visitor centre at 85 m elevation was built on the site of Ballysop House. The buildings are long and low, designed to blend into the landscape and they won an An Taisce award in 1970. There is a reception hall with displays, a lecture hall with the audio-visual show, toilet block and offices. Western red cedar was used externally and was left untreated to weather naturally, but some of it has decayed so it has been replaced by Iroko (*Milicia excels* (Welw.) C. Berg). Parana pine (*Araucaria angustifolia* (Bertol.) Kuntze) was used for the ceilings. The walls were of sandstone block and paving of limestone flag, both from Liscannor in Co. Clare. The roof was a copper faced membrane, which turns green with age.

The focal point is the memorial fountain, a single block of Wicklow granite with the words of President Kennedy: "ask not what your country can do for you…ask what you can do for your country".

Other structures

These include four shelters, one with a toilet block, at intervals around the Arboretum road, constructed of the same materials as the visitor centre. There is a tearoom and shop a short distance from the car park, built of western red cedar and with a felt roof. Across the main road is the service centre which contains the staff canteen, toilets and showers.

Sale of produce

In addition to the standard gate charges, other forms of income generation have been attempted. Revenue from these sources accounted for approximately 20% of total income in the past, but only timber sales and letting of grazing continue today.

- Timber – This is produced from thinnings of forest plots, shelter belts and woodlands, and from trees blown down in storms. It is sold mainly as firewood, with some sold as poles. There will be a greater proportion of sawlog timber as trees grow in size.
- Christmas trees – Areas which must be kept free of tall plants, e.g. near the Meteorological Station, seemed ideal for growing Christmas trees. However, the scale was too small for it to be viable.
- Shrubs – The sale of shrubs was attempted on a small scale, but was unsuccessful. To be a viable operation, more staff would be required to manage it and as a much larger operation.
- Foliage – There is a small but steady demand for foliage, from florists.
- Mulch – This is made from branches which are too light for timber. Mulch was sold in the past, but currently all of it is used in the maintenance of the arboretum.
- Grazing – Letting of sheep-grazing is done in the Extension Area.

The arboretum is open throughout the year, except Christmas Day and Good Friday. Its appearance changes with the seasons, making it attractive for visitors year round. About 90,000 visitors come each year. In early summer, a blaze of scarlet flowers of the Chilean fire bush (*Embothrium coccineum* Forst. and Forst. f.) against dark woodland, golden ash (*Fraxinus excelsior* L. *"Jaspidea"*) gleaming behind a shelter belt; and weeping purple beech (*Fagus sylvatica* L. "*Purpurea Pendula"*), contrasting with the upright and golden forms, can be seen from the arboretum road.

Later in the year the autumn colour is spectacular – the red of Japanese maples (*Acer palmatum* Thunb.) seen against mature woodland; the scarlet of the Sargent's Mountain Ash (*Sorbus sargentiana* Koehne), with the blue-leaved Sitka spruce behind and even the shelter belts themselves with red oak (*Quercus rubra* L.) and Japanese larch (*Larix kaempferi* (Lamb.) Carr.), contrasting wildly with grand fir (*Abies grandis* (Dougl. ex D. Don) Lindl.) and Lawson cypress (*Chamaecyparis lawsoniana* (A. Murr.) Parl.).

As one of the gardens in State care, it will continue to mature and serve the role for which it was established.

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Trees Woods and Literature – 37

Launch of "The Trees of Great Britain and Ireland"

National Botanic Gardens, 6th March 2013

The following is a report from the launch of the reprinted version of *The Trees* of Great Britain and Ireland (Figure 1). The President, John Mc Loughlin, welcomed everyone to the book-launch at the National Botanic Gardens and in particular Sir Henry Elwes, great-grandson of Henry John Elwes who together with Augustine Henry co-wrote "The Trees of Great Britain and Ireland" (commonly called *The Trees*). It was originally published privately between 1906 and 1913, a monumental work in seven volumes plus an index. To celebrate its 70th anniversary, the Society of Irish Foresters decided to publish this limited edition reprint of Elwes and Henry's masterpiece. It is now 100 years since the publication was first completed in 1913. It is also a 100 years since the Faculty of Forestry was established at UCD (then the Royal College of Science), where Augustine Henry became the first Professor of Forestry. The Society plans to celebrate this anniversary later this year.

The Society of Irish Foresters always had an interest in *The Trees*. The first

Figure 1: *Sir Henry Elwes (third from left), great grandson of Sir John Henry Elwes, co-author of The Trees of Great Britain and Ireland, the editorial committee of Donal Magner, John Mc Loughlin, Kevin Hutchinson and Pat O'Sullivan, with Matthew Jebb, Director, National Botanic Gardens, Glasnevin at the launch on 6th March.*

edition of its technical journal *Irish Forestry*, Vol. 1, No. 1 included an abstract from the book, and the species chosen was *Arbutus*. The Society is delighted to make the book available to a wider audience at a reasonable price; since only 300 copies were printed originally it was always difficult to acquire a copy. It is important to thank the members of the Society's sub-committee, Kevin Hutchinson, Donal Magner and Pat O'Sullivan for ensuring that a high quality publication was delivered on time. Donal Magner was particularly thanked for his attention to detail in arranging the facsimile copies, which resulted in an excellent publication (see Figure 2).

A century after its original publication, the book is as relevant today as when it was first published, the only changes are that taxonomists have altered the scientific names of some trees. One of those, Dr Matthew Jebb, Director of the National Botanic Gardens, was introduced to speak about Augustine Henry. Dr Matthew Jebb, after being thanked warmly and particularly for allowing access to the National Botanic Garden's set of *The Trees* for the scanning process, spoke about Augustine Henry:

> Augustine Henry was, by comparison to Henry John Elwes, almost painfully modest and patient. He would be embarrassed with today's activity. He scarcely mentioned the rigours and adventures of his 18 years in China, certainly never in print. A medical man by training, a customs officer by profession and a botanist and forester by wont, sums up Henry's remarkable life. The writing of *The Trees* formed an interlude between his days as a customs official working for the Imperial Maritime Customs Service in China and his later career as the first Professor of Forestry at the College of Science in Dublin.

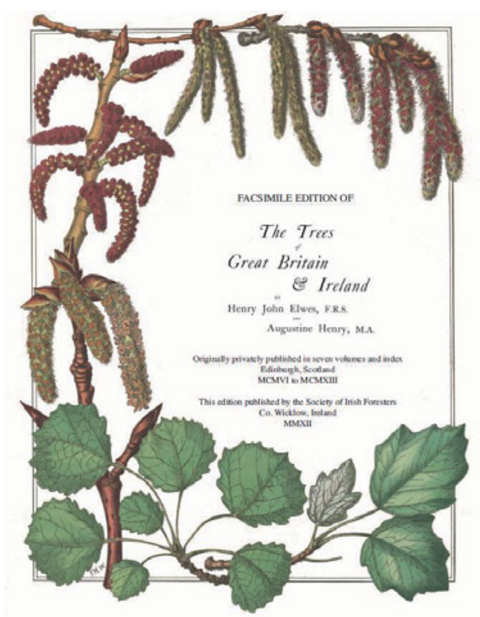


Figure 2: *The frontispiece from* The Trees of Great Britain and Ireland.

Augustine Henry was of the view that a hereditary wealthy class justified its existence by being a breeding ground of individualists, and no doubt their pre-eminence as collectors of trees. Indeed some of the greatest tree collections in these islands began, and many still remain, in private hands. Trees transcend human generations, and without the permanency of a plot of land, which will remain in the family, such collections cannot begin or survive. The zeal for building a collection of living trees depends not just on land, but also upon an epiphany or defining moment in the arboriphile's life.

That moment came for Augustine Henry (1857–1930) towards the end of his years in China when he witnessed the transformation of the frontier region between what was then French Indo-China, currently Vietnam, and the Chinese province of Yunnan. Up until that time he had revelled in the largely untouched forests of central China. He wrote to his long-time correspondent Evelyn Gleeson in 1899 that 'a forest is the finest thing in the world'. It was near the town of Szemao in Yunnan, that he was suddenly shocked by the rate at which the forests had begun to disappear as this frontier was opened up to trade. To that point the forests of central China had seemed as vast as to be immune to destruction. In his last years in China he worked hard to persuade Kew and then Harvard to send plant collectors. In the end it was Thiselton-Dyer of Kew who interested Veitch & Sons, a nursery that had done well out of the Giant Sequoia (*Sequoiadendron giganteum* (Lindl.) J.T.Buchholz) many years earlier, to send a young collector, Ernest Wilson to China. Wilson spent some months with Henry in Yunnan, and was inculcated with the field craft of the plant explorer. It seems probable that Henry felt great comfort in having passed on this mantle of duty towards the Chinese flora, and gave him the resolve to finally resign his post as a Chinese customs official and return to Europe.

The backgrounds and temperaments of Henry and Elwes could hardly have been more different, but their passion for trees was well matched. They both understood that no publisher could appreciate the importance of their mission, and the work would need to be privately printed to ensure their absolute control. The eccentric order of genera is a testament to this remarkable drive for thoroughness – starting with *Fagus*, the first volume veers to *Sophora* by way of *Ailanthus*, and then to *Araucaria* and onwards to *Ginkgo*. Many of the larger genera are visited multiple times throughout the volumes. As Henry explained in the postscript to the work, the want of order was of the greatest service to them, enabling them to leave the more difficult and least known genera till last, by which time they had become better acquainted with them. The scale of the endeavour grew as work progressed, and their initial plan of five volumes soon grew to seven. The all-important index volume gave access to the knowledge that any reader could require.

Their zeal ensured they took pains to visit every estate they could in Britain and Ireland, to see the trees with their own eyes and record on the spot. Elwes never took any evidence second hand, and the two criss-crossed Europe to satisfy themselves on the smallest of points. Elwes famously claimed that they wore out two motor cars writing *The Trees*. Sir Frederick Moore's obituary of Henry reports two motoring accidents in the short space of time he joined them during one such tour, so fair wear-and-tear may have been the least of their problems. Elwes employed Henry for much of the time the volumes took to reach completion. This was always a difficult point, since Henry was parsimonious in his dealings with money, and he took great care to consult others before entering his contract with Elwes. Elwes on the other hand was wealthy and generous to a fault. The first volume appeared in 1906, three years after their work began, followed at yearly intervals by the next four, while volumes six and seven experienced some delay. But after ten years, the seventh volume appeared in the middle of July 1913, and the great work was complete. It stands today as a wonderful memorial to two very different, but equally inspiring men who have left us a magnificent testament to their industry and insight.

Then Sir Henry Elwes spoke of his great-grandfather:

I am very honoured to have been asked to join you on this occasion and to assist in the launch of this first class reproduction of *The Trees of Great Britain and Ireland* and to say a few words about my Great-Grandfather.

From the age of 17 until the year before he died, aged 76, Henry John Elwes never spent an unbroken year in England, such was his interest in all about him. He first studied birds, beginning with a visit to the Outer Hebrides at the age of 17 to study wildfowl with naturalist and later brother-in-law, Frederick Godman - quite an excursion in the 1860s! He was hired by Hooker's Journals to look further afield and made his first trip to India and the Himalayas at the age of 23 and followed this by several more trips. He was awarded Fellowship of the Royal Society, one of only two non-academics, at a very young age for his work on the "*Distribution of Asiatic Birds*". He also collected butterflies and 20,000 are now in the Natural History Museum in London and it was his new wife, fed up with a house full of bird skins, who persuaded him to look at plants!

An early find was the first large snowdrop ever collected, in 1874, and now bears his name *Galanthus elwesii*. At Colesbourne Park (Gloucestershire) we now have one of the biggest collections of snowdrops in the United Kingdom with 250 varieties. Henry John's collection of bulbous plants was said to be the largest private collection in the world and he provided more than 100 specimens for description in the *Botanical Magazine*. It was said that if Kew couldn't recognise a plant it was sent to "old Mr Elwes because he had probably seen it in the wild, somewhere in the world".

But as well as all this he was a responsible landlord and looked after his tenants well. He was a visionary farmer himself, he served as a magistrate and he liked nothing better than a good day's foxhunting over the Cotswold Hills. He also hunted big game all through his life. He planted around 850 acres of new woods and created a very special arboretum at Colesbourne

Park. I still have his pocket book recording 470 trees, detailing where he collected them from and where he planted them! An example is a *Cryptomeria japonica* seedling collected and brought home on the Trans-Siberian Railway (a three week journey) and then planted '20 yards from ice-house'. It is still growing there! In fact, it was trees that took up the last 20 years of his life. He was inspired after an 8,000 mile trip through Eastern America, then Mexico where Frederick Godman guided him through the forests of Southern Mexico, and finally up the west coast of America ending up in Wyoming.

In the 1880s England was facing a bad agricultural depression and Henry John Elwes was forced to lay out rabbit warrens and let the shooting rights for £10/- an acre when farm tenants could not afford any rent and were allowed to remain in their farmhouses free of charge. He then hit upon the idea of forestry as a better alternative use of land but, finding no book on the subject apart from Evelyn's *Sylva* of 1776 and Loudon's 1838 work mostly copied from others, he decided to write one himself, based on his own personal study and observation. He was not a botanist and so invited Thistleton-Dyer, Director of Kew, to suggest someone to help and the name of Augustine Henry, a customs officer and ardent botanist, who had just returned from many years in China, came up.

Henry John Elwes was described as a massive framed man with a handsome dark beard, a boyish love of adventure and astonishing powers of observation and memory. Here were two complete opposites who worked together for 12 years with virtually no disagreement. This must have been a challenge because Henry John Elwes was described by others as 'someone who had little knowledge of the art of compromise'! I wonder, was Augustine wholly acquiescent? I doubt it, but he had exact botanical science on his side, and this could hardly be challenged by a mere observer! After much travel and the wearing out of several cars this unusual partnership produced an incredible book: informative, accurate, and totally readable and of enduring value.

Henry John Elwes came down to breakfast one day and said to his wife Margaret, "Will you get the ham rolled up for me because I must go and see the Chile pine growing in its natural habitat for the book and I will be back in about three months"! The fact that *The Trees* has now been re-published after 100 years and with no amendments is testament to the astonishing achievement of 12 years' intense study. The authors would be proud of this occasion as indeed you all are of your premier Irish plants-man, Augustine Henry, and I am of my great-grandfather Henry John Elwes.

I thank your Society for inviting me to be with you today and I am delighted now to launch this book and to congratulate you on a magnificent undertaking and I wish you every success with the production.

The President thanked the speakers and made a presentation on behalf of the Society. All were then invited for light refreshment.

John McLoughlin and Pat OSullivan

Book Reviews

A list of recently published books on trees and forestry, which may be of interest to members, is provided below. Reviews of three books from the list (marked with an asterisk) are included in this section.

List of publications of interest to SIF members

Conifers Around the World. Two volumes by Zsolt Debreczy and Istuan Racz. Published by Dendro Press. 2011. *Available.*

RHS Encyclopaedia of Conifers by Aris G. Anders and Derek P. Spicer. Published by Royal Horticultural Society. 2012. *Available.*

The Trees of Great Britain and Ireland by Henry John Elwes and Augustine Henry. A limited facsimile edition published by the Society of Irish Foresters. 2012. *Available*.

***The Silviculture of Trees Used in British Forestry**, 2nd Edition. Peter Savill. Published by CABI. 2013. *Available*. [Reviewed]

***Infectious Forest Diseases** by Paulo Gonthier and Giovanni Nicolotti. Published by CABI. 2013. *Available.* [Reviewed]

Ginkgo: The Tree that Time Forgot by Peter Crane and Peter Raven. Published by Yale University Press. 2013. *Available.*

The Genus Betula: A Taxonomic Revision of Birches by Kenneth Ashburner and Hugh McAllister. Published by Royal Botanic Gardens, Kew. 2013. *Available.*

Oak by Peter Young. Published by Reaktion Books. 2013. *Available*.

Plant Roots – the Hidden Half, 4th Edition. Edited by Amram Eshel and Tom Beeckman. Published by CRC Press, Taylor and Francis Group. 2013. *Available*.

Tales, Traditions and Folklore of Ireland's Trees by Ben Simon. Published by The Forest of Belfast. 2013. *Available*.

Ireland's Woodland Heritage – A Guide to Ireland's Native Woodlands by John Cross. Published by Department of Arts, Heritage and the Gaeltacht. 2013. *Available.*

***A Guide To The Valuation of Commercial Forest Plantations** by H. Phillips, J. Phelan, D. Little and T. McDonald. Published by COFORD. 2013. *Available.*

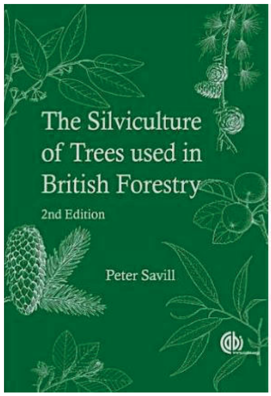
Pine by Laura Mason. Published by Reaktion Books. *Available August 2013.*

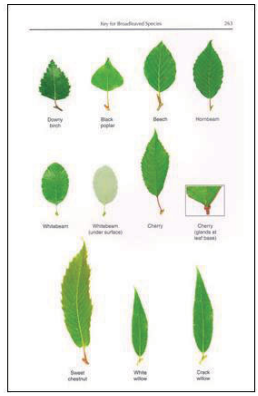
The CABI Encyclopaedia of Forest Trees. Published by CABI. *Available September 2013.*

Yew by Fred Hagender. Published by Reaktion Books. *Available October 2013.*

The Silviculture of Trees Used in British Forestry

Peter Savill. CABI Publishing. 2013.
ISBN 978-1-78064-026-6. Hardcover, 288 pp
€100





The author Dr Peter Savill, a former lecturer on silviculture at the University of Oxford and more recently a Reader in Silviculture at the University of Oxford, is no stranger to Irish forestry, having worked with the Research Branch of the Forest Service in Northern Ireland for almost twenty years. When he first published *The Silviculture of Trees Used in British Forestry* in 1991, it became an immediate bestseller among foresters and all those associated with forestry. Since its publication it has also become an important reference source as well as a "bible" for all those who worked with or had an interest in trees and forestry in the UK. Similarly, in Ireland it too became an essential species guide for the forestry fraternity and anyone interested in trees and forestry. Since then it has been reprinted on several occasions and, just recently, it has been completely revised and updated and a new second edition has been published. As with the original publication, the new edition is also a must for anyone interested in forestry and all those with an interest in the wide range of trees found in forests in these islands.

The original edition was quite an extensive publication, covered almost sixty species and amounted to 145 pages of text. However, the new edition has been substantially expanded and covers sixty three species and extends to 280 pages. The author acknowledges the wide range of books published on trees that grow in Britain and mentions earlier publications such as Alan Mitchell's (1974) *A Field Guide to the Trees of Britain and Northern Europe* and more recently Thomas Pakenham's (1996) *Meetings with Remarkable Trees* as well as numerous tree guides published by the Forestry Commission over recent years.

In the Introduction, Dr Savill highlights a number of key considerations when deciding on the choice of an individual species. These include the importance of matching species to the site where the trees are to be grown as well as the critically important consideration of provenance choice, which is now of even greater importance due to the growing uncertainty of future climate change. The original edition presented data on the area and percentage of total forest by species in the UK in the 1980s and this has been reviewed and updated to provide readers with comprehensive information on the areas of high forest in the UK for the principal species growing there, based on information gleaned from the National Inventory of Woodland and Trees 1995 - 1998. A new feature in the 2nd edition is a review of important developments in British forestry since the publication of the original edition to the present day, much of which also mirrors developments in Irish forestry. It also highlights development in the changing attitudes of the public to non-native species and the use of conifer and broadleaf species. Other changes reflected in this section include the important question of profitability of forestry, as well as the ever threatening spread of pests and diseases. Another important area which the author highlights is the growing problem caused by some of the most recent serious diseases introduced to Great Britain and discusses recent developments. The author concludes this section with an outline of what the new edition hopes to achieve, which is "to provide a guide for use in selecting species and for the management of trees". Here the requirements of individual trees are described along with situations in which they are likely to do well; however, no particular consideration has been given to the relative economics of the different species. The main emphasis is on the biological suitability of individual species to particular site types and here it is assumed that the reader is reasonably well informed on the principles of forestry practice.

According to Dr Savill, Mitchell (1974) reported that about 35 species of trees are native to Britain. However, he suggests that over 500 species can be encountered by anyone looking in parks and gardens, and if special collections in botanical gardens and arboreta are included, the number rises to over 1,700. The author states that 35 genera and 63 species are dealt with in the revised publication, but these selections have inevitably been arbitrary and goes on to explain that "because of current interest as well as the growing emphasis on conservation, almost all native species that grow to reasonable sized trees have been included in the new publication".

The species dealt with in the new edition are set out in alphabetical order based on their botanical name, commencing with *Abies alba* (European silver fir) and concluding with *Ulmus procera* (English elm). Each species' description is supported by very detailed botanical diagrams of the species' leaves and fruit (flowers and seed), expertly drawn by Rosemary Wise, as was the case in the earlier edition. Each species is generally treated in the text under a number of key headings such as: (1) origin, (2) climate requirements, (3) site requirements, (4) other silvicultural characteristics, (5) pests and diseases, (6) natural regeneration, (7) flowering, seed production and nursery conditions, (8) provenance and improved seed, (9) area, yield and rotation length, (10) timber and (11) place of the species in British forestry. The text is presented in a reader-friendly, easily understood style and avoids using technical terms except where it is necessary to do so.

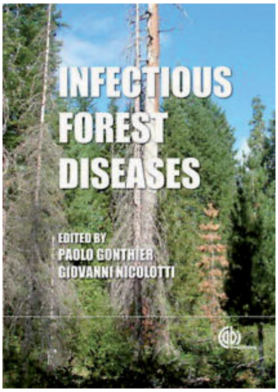
Another useful addition to the second edition is a field key for identification of common forest and woodland trees, which covers 28 broadleaved species and 14 conifers and is supported by a simple but useful method on how to use the key, which will no doubt be a very practical addition for the lay person with an interest in tree identification. To use the key one first decides whether the tree is in the broadleaf or coniferous category, then it guides the reader in the identification of the particular species. To support the identification process a colour plate of the individual foliage (a single leaf) of each species is provided for the reader.

The new edition, like the first edition, is published by CAB International. The cost of the original paperback edition was only £29.95, while the new edition which is only in hardback costs £75.00. However, it is expected that a paperback version of this new second edition will be published early next year but the price of this version is not yet available.

John Fennessy
Chairman of the Future Trees Trust Oak Improvement Programme

Infectious Forest Diseases

Paolo Gonthier and Giovanni Nicolotti (Eds). CABI. 2013.
672 pages. Hardback. ISBN 978 1 78064 040 2
€199



In recent times, forest diseases and pests have come to the fore due to their increasing frequency and intensity (see McCracken 2013 – this issue). This year alone several forest disease themed seminars have been organised, including many by the Society of Irish Foresters. How we respond to these disease threats is a key challenge for sustainable land-use and rural economics; indeed, the control and management of these plant diseases has been identified as one of the key challenges facing plant scientists in the current era (Grierson et al. 2011[1]).

The recent CABI publication *Infectious Forest Diseases* (2013), edited by Dr Paolo Gonthier and the late Dr Giovanni Nicolotti, both of University of Torino, Italy, is reviewed here. Superficially the book is an impressive tome, hard bound and numbering 672 pages. Furthermore, the book is rather expensive, at €199 from the publisher's website. However, some solace regarding the price can be taken from the fact that the publisher is a not-for-profit organisation, and that a portion of the funds generated are pumped back into plant health research and initiatives that benefit plant scientists and growers worldwide. Incidentally, one such initiative that may be of interest to *Irish Forestry* readers is the Plantwise web-based Knowledge Bank (www.plantwise.org), which includes a disease diagnostic tool and pest information sheets on hundreds of pests and pathogens worldwide. Furthermore, the system is a self-learning one, where users can input symptoms to identify the possible pests or pathogens - this information is then mapped, thus providing

[1] Grierson, C.S. Barnes, S.R., Chase, M.W., Clarke, M., Grierson, D., Edwards, K.J., Jellis, G.J., Jones, J.D., Knapp, S., Oldroyd, G., Poppy, G., Temple, P., Williams, R., Bastow, R. 2011. One hundred important questions facing plant science research. *New Phytologist* 192: 6–12.

updated information on the pathogens host range and global distribution to future users of the system.

To get back to the book, it is composed of 28 chapters authored by 57 experts in the respective diseases or specialists within forest pathology. These chapters are grouped into five sections:

- Introductory concepts;
- Non fungal forest diseases;
- Fungal and fungal-like forest diseases;
- Nursery diseases and Introduced pathogens.

From this description it may be apparent that the insect pests do not fit into any of the previous sections - the book chooses not to deal with these at all. In my opinion this is a good choice, not only because of the already large numbers of pages but also because insect pests of forests are dealt with sufficiently in other books. It is not practical to provide details on all 28 chapters, however, I will briefly expand on several chapters I feel would be of particular interest to *Irish Forestry* readers.

The first section contains only two chapters, the first dealing with the concepts of epidemiology of forest diseases and the second with general management strategies for coping with infected forests. Both chapters are important reading for the present-day forester, as they provide a good grounding in the general concepts of disease epidemiology in forests and of the methods used to control disease outbreaks. Chapter 1 is very well written, explaining the general concepts of disease epidemiology using real world examples abundantly throughout. Explanation of uncommon terms and the scientific language used makes this book accessible to the non-pathologists among us - indeed the book as a whole is made very accessible thanks to the frequent explanation of terms. Chapter 2 provides an overview to the current strategies for managing disease in forests. This chapter also sets the scene for the rest of the book, by outlining the general headings under which each subsequent chapter will proceed. The standard template used in all subsequent chapters, and the frequent citing of the other chapters within this book gives it a noticeable inter-chapter connectivity, which is in my view a trademark of good editing.

The disease chapters that will no doubt be of interest to *Irish Forestry* readers are the chapters describing pine wilt diseases (e.g. pine wilt nematode), *Dothistroma* needle blight (red band needle blight), foliar diseases of broadleaved trees (e.g. *Chalara fraxinea*), oomycete diseases (e.g. *Phytophthora ramorum*, *P. kernoviae*) and there is an entire section on root and butt rots (e.g. Fomes stem rot, honey fungus rot). As mentioned previously, all chapters follow a standard template, which greatly aids in navigation through this large and information packed book.

The penultimate chapter, namely Seed, Seedling and Nursery Diseases, is a vital inclusion to this book. As explained in the final chapter, Responding to Diseases Caused by Exotic Pathogens, nurseries and the plant trade are the main vector for the long distance spread of many exotic pathogens world-wide. The final chapter is one of my own personal favourites, written by a well-respected expert in modelling and forecasting population dynamics, Dr Marco Pautasso. This chapter highlights how the international plant trade network is one of the main factors in spreading exotic pathogens (elegantly illustrated by the Figure on page 596). I also find this author's perception of the disparities in plant health monitoring across member state borders in Europe amusing, as he states that "Luckily different countries and cultures will tend to deal with the problem in different ways, a diversity to be welcomed because it could avoid the making of the same mistakes all over the planet".

On the whole, I am especially drawn to this book because of my previous experience in forest ecology. The book acknowledges that many of the pests dealt with only prove to be problematic when taken out of their own native ecosystems. In their natural habitat these disease-causing organisms play an integral part in regulating an ecosystem and in ensuring that diversity is fostered. A good example of this is how some species of *Pythium* (an oomycete) ensure that a tree's offspring do not succeed under the canopy of the parent tree – ensuring tree species diversity throughout the forest (see page 520). The book also encourages the use of species diversification to buffer against disease epidemics in forests, a strategy that would also increase biodiversity (O'Hanlon and Harrington 2011[2]).

In comparison to similar texts, this book compares very well. In my opinion the literature on forest pathology has been calling out for a book such as this for a number of years. This book provides an up-to-date summary of the developments in the biology and management of a number of important forest pests and diseases, focussing mainly on northern hemisphere temperate forests. It is here where I see the main value of this book lies. It can be difficult and time-intensive to keep abreast with the developments in the understanding of forest pathogens. There are several learned journals that regularly publish articles on forest pathology (e.g. *Forest Pathology*, *Plant Pathology, Phytopathology, European Journal of Forest Research)* and numerous others that include forest pathology within their broader remit (e.g. *New Phytologist, PLOS Pathogens, Forest Ecology and Management*). This book provides readers with excellent summaries on the current understanding of many forest pathogens, and three chapters dealing with general concepts of disease epidemiology in forests, disease management practices for forests, and exotic diseases of forests.

Two minor criticisms I have are the high price, and also the low coverage given to the ash dieback pathogen, *Chalara fraxinea*. This is a surprising fact given that one of the chapter authors is the scientist that first described this pathogen in 2006[3]; however, it is evident throughout that the books focus is on diseases at a larger scale than that of a single species. Still, these criticisms are minor and otherwise I find this to be an excellent addition to the literature on forest pathology.

Overall, I can recommend this book to *Irish Forestry* readers who have a keen interest in current forest pathogens – which probably includes the vast majority of readers.

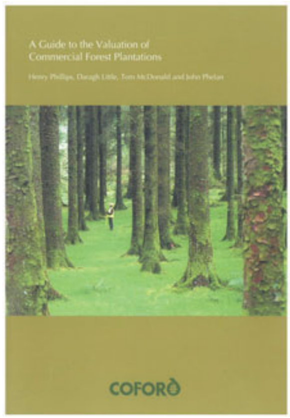
Richard O'Hanlon
www.rohanlon.org

[2] O'Hanlon, R. and Harrington, T.J. 2011. The macrofungal component of biodiversity in Irish Sitka spruce forests. *Irish Forestry* 68: 41–54.

[3] Kowalski, T. 2006. Chalara fraxinea spp now associated with dieback of ash (Fraxinus excelsior) in Poland. Forest Pathology 36: 264–270.

A Guide to the Valuation of Commercial Forest Plantations

Phillips, H., Little, D., McDonald, T. and Phelan, J.
COFORD. 2013.
Softbound. ISBN 978-1-902696-72-0
€20



The expansion of the forest estate, especially the increased number of private forest owners, will result in a greater need for the valuation of forest plantations, not only for sales purposes, but also for investment, insurance, financial reporting and other reasons. Therefore, the publication of The *Guide to the Valuation of Commercial Forest Plantations* by COFORD comes at an opportune time. The important role that forests can play in the national recovery, as well as in the mitigation of climate change through carbon sequestration, the provision of renewable energy, and the wide range of ecosystem goods and services that they can provide to the owners and society, has put a new emphasis on the proper valuation and financial management of this resource that now covers more than 10% of the land area in the country.

The publication begins with an almost two-page long glossary of acronyms used in the book. During my subsequent read of the book, I frequently had to refer to this list, to refresh my memory of the large range of acronyms used. The separate glossary of terminology, which appears at the end of the publication before the Appendices, should have been included together with the glossary of acronyms at the start of the text, as I only discovered it when I reached the end of the book.

The Executive Summary is almost seven and a half pages long and was not easy to get through. The summary gives a complete overview of the material in the book in a structured and logical manner. However, the density of information, and also of the layout and presentation, made it hard work to fully comprehend the information contained in it. I would have preferred a more "light-weight" summary, with frequent linkages to the detail in the actual report. This would, in my opinion, make the book more accessible to readers, many of whom are probably not very familiar with the details of financial analysis.

The main body of the book consist of 11 chapters, organised in a very logical way, starting with an Introduction (Ch 1) and progressing into the background of valuation (Ch 2), and the actual valuation methods (Ch 3), including the International Accounting Standard 41 (Ch 4). The subsequent chapters deal with specific inputs into the valuation process, such as the value of land (Ch 5), revenues and costs (Ch 6), forecasting timber volumes (Ch 7), the discount rate (Ch 8) risk (Ch 9), and special considerations such as the sale of bare forest land and broadleaf stands (Ch 10). The final chapter (Ch 11) covers the preparation and execution of a forest valuation, including the all-important valuation report. I felt these chapters were very clearly presented, dealing with each issue in a transparent and easy-to-follow manner. I particularly enjoyed the chapter on valuation methods, where each method is introduced and benefits and disadvantages are presented.

The chapter on the forecasting of timber volumes and the identification of a series of crucial factors that need to be included in this forecasting process is especially relevant. These factors include open space, attrition, harvest loss and product outturn. A chapter that I was rather disappointed with is the one dealing with discount rates. All the important information is included here, but after reading this chapter several times, I am none the wiser as to which discount rate should be used in valuation projects. It is of course true that there is no one correct rate to use, and examples of rates applied in different countries and for different scenarios are presented, but to some extent the reader could conclude after reading this chapter that any discount rate will do, and that rates can be selected to produce the results that one is looking for. This has always been a controversial issue in forest economics, with individuals and organisations justifying the use of a particular rate based on the fact that the outcome of the analysis with that rate was the preferred one. As is mentioned, high discount rates favour short-term projects while low rates favour long-term projects. Actually, high rates have a negative impact on the discounted cash flow or net present value (NPV) for both short- and long-term projects, but for long-term projects this impact is greater. The opposite is true for low discount rates. But all of this is irrelevant, as the choice of discount rate should not be based on the outcome, but on the inputs. As is clearly stated, the discount rate should be made up of a risk-free component and a risk rate. These should be chosen based on market values, the time preference level of the owner, and on the assessment of the riskiness of the particular project. It is true that for certain long-term projects a lower discount can be justified, but this is only the case if economic efficiency needs to be balanced against intergenerational equity, as for instance in the social cost-benefit analysis of climate change mitigation, and the resulting social discount rate should be applied in a step-wise manner, with the standard rate applied to the first period (say 30 years), and then a lower rate to the next period, and so on, as for instance recommended by the UK Government (e.g. http://www.dfpni.gov.uk/eag_net_present_values). In terms of risk, the book includes the useful suggestion that, as much as possible, risk should be taken out of the discount rate and dealt with by including factors such as wind, fire and the markets, in the actual analysis. This leaves only the systematic or non-diversifiable risk component that needs to be incorporated in the discount rate itself. Very important, and maybe not sufficiently emphasised, is the need to prevent risk from being "double counted" or even "triple counted", first by including it in the discount rate, then as separate elements in the valuation process, and finally by including insurance costs in the cash flow, that are actually incurred to reduce the overall risk level.

Of course a book dealing with forest valuation cannot be complete without the introduction of Land Expectation Value (LEV). This very interesting, and I feel, useful concept is rather downplayed. The fact that it is based on the idea of a perpetual series of similar rotations makes it initially rather abstract, but the same is true in many ways for the Annual Equivalent Value (AEV). Here the net present value of a single rotation is expressed as an AEV to allow for comparisons of project with different (rotation) lengths. The questions arise: What happens after that rotation? What is the value of the land? What use will be made of the land? The answers to these questions will of course have an impact on the overall valuation of the project. I also had a problem with the section dealing with the potential for a negative LEV. In the book, a negative LEV is assumed not to be realistic, expressing a negative value of the land, and remedies are suggested including using a lower discount rate. However, a negative LEV can only result from a negative NPV. A negative NPV indicates that a particular investment or project is earning a rate of return which is lower that the discount rate used, identifying that the project should not go ahead (unless non-financial reasons justify this). A negative LEV indicates the same thing: the land has a negative value for the particular forestry scenario analysed. Finally, in relation to the LEV, a worked LEV example in Appendix 2 includes the cost of upgrading the road at age 17 (i.e. a year before first thinning). I assume this cost relates to the upgrading of a low-quality establishment road to a timber haulage road. This cost should probably not be included in the analysis, as inclusion assumes that a similar road upgrade will occur in year 17 of each rotation. The road construction and upgrade costs should be kept out of the LEV calculation, similar to the cost of the land, and should be incorporated in the analysis afterwards. On the other hand, regular recurring road maintenance costs should be included in the LEV calculation itself.

Finally, I would have liked it if the authors had included more details on the valuation of non-timber ecosystem goods and services. Nowadays, with the emphasis on sustainable forest management and multi-functional land use, it would have been useful to inform the readers about the progress in the development of methods to value carbon sequestration, recreation, biodiversity, water quality and quantity, and other (positive and negative) outputs. In this context, I also would recommend that the term "crop" is not used; foresters manage forests and stands, and valuation should also relate to the stand and not just the crop.

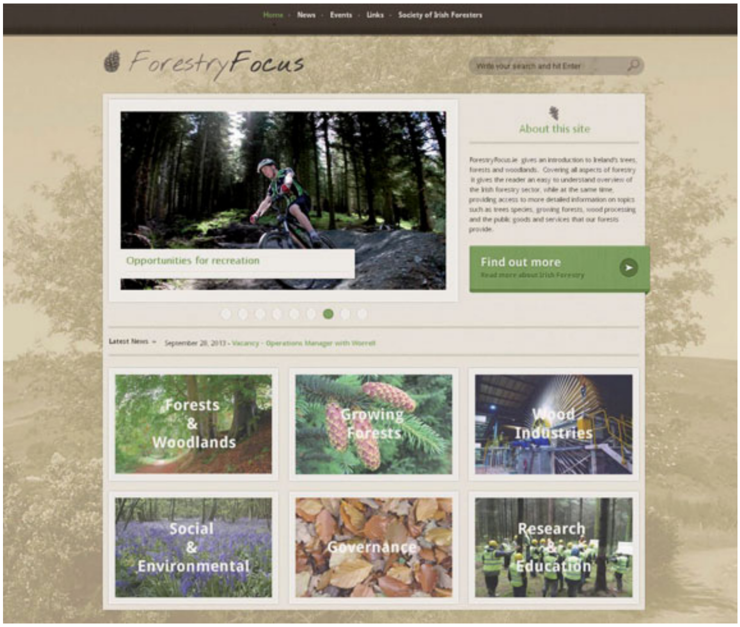
Unfortunately there are quite a few typographical and syntax errors in the text and, even more importantly, errors in the formulas included. For instance, the LEV formulas on page 26 include the t variable as a multiplier (the formula is correct in

Appendix 2), while this should be as an exponential. The same is true for the PV formula on page 18. In the formula in Appendix 4, there is confusion about the use of *i*, *idr* and i_{dr}.

As is obvious from the above, I have quite a few issues with the publication, but this is only to be expected given the complexity and often subjectivity of the concepts and assumptions behind valuation methods. Overall I think it is very important that this book has been published and that foresters and forest owners can get a basic understanding of the valuation process and of the multiple and often complex parameters and factors that go into it. I therefore recommend that all professional foresters and interested forest owners obtain a copy of this publication, while being cognisant of the issues raised in this review.

Prof. Maarten Nieuwenhuis
UCD Forestry

ForestryFocus.ie



The new Forestry focus website is an informative and comprehensive resource for many aspects relating to Irish forestry such as the timber industry in Ireland, forest governance, and social and environmental issues. The site is very easy to negotiate.

There is an excellent section on the history of Irish Forestry. However it contains a lot of information which does not directly pertain to forests and a shorter summary of forest related information might be useful. Perhaps a simple timeline graphic showing forest cover and very significant historic events might be useful (although I am not sure how easy it would be to produce). It is also not so easy (for example) to see how forests in modern times differ from those felled in the 16^{th} and 17^{th} Centuries.

As a scientist, I found the links to the Irish forest inventory data, summary statistics and news on development of *Chalara fraxinea* in Ireland very good. However, it would be good to be able to see at a glance on the main website, the forest area in Ireland, or how much area (approximately) is Sitka spruce, oak etc.

The section on forest management describing different silvicultural systems, fertilising, weed management, tending and thinning etc. is an excellent resource for the forest owner.

Every time I thought I had seen most of the website, I found another interesting page, it really is very comprehensive.

Dr Joanne Fitzgerald

Senior Researcher with the Sustainability and Climate Change Unit of the EFI, Finland.

Management of Irregular Forests – Developing the full potential of the forest

Susse, R., Allegrini, C., Bruciamacchie, M. and Burrus, R.
English Translation: Phil Morgan
Association Futaie Irrégulière, 24 quai Vauban, 25000
Besançon, France. 2011.
ISBN 978-2-9538331-1-9
€22

The preface to this book asks some fundamental questions that are beginning to be raised amongst the thousands of new Irish forest owners. “When you own a forest, the question of how you pass it on invariably arises. In what condition should it be maintained? Does one need to spend money? What should one harvest? In short how does one at the same time profit from one’s woodland and leave it in good condition?”

The answers to these questions are cached in this useful book, which is a pioneering document on the management of irregular forests or, as it has become known in Ireland, continuous cover forestry. The book has already become valuable to those practicing irregular forestry in Ireland as a handbook in forest management and planning. It has also become useful as a reference for newcomers to irregular forest management as it provides a justification for, and technical yet understandable background, to this type of management.

One of the difficulties faced by proponents of irregular forestry has been that this kind of management does not lend itself to conventional experimental design and replicated trials in the same way as rotational plantation forests do. Managers follow a set of principals rather than prescriptions and these are interpreted on any site or in any forest type using the foresters experience and instinct. This has meant that, although its advocates are convinced they are making good forest management decisions, it has been difficult to present scientific evidence of the merits of irregular forest management systems in terms of yield, economics, ecology etc.

This fact was acknowledged by a group of private French foresters in the late 1980s who founded the *Association Futaie Irrégulière* (AFI). They wrote an inventory protocol, using permanent sample points, to periodically record the state of irregular forests and the effect of forest management decisions in such a way that reflects the multifunctional services these forests provide. The inventory is repeated on a five-year basis. All intervening inputs (including management and operational costs) and outputs (including timber volumes and revenues) are carefully recorded. The protocol is described in this book and has been applied in over 90 research stands across France, and now in other countries including Ireland, where there are six AFI stands. These stands are also used for demonstration and training purposes.

This book provides the results from selected stands from the AFI network that have been closely monitored for twenty years. The power of the network is clearly evident in displaying incremental, economic and ecological trends. It is more powerful again for forest owners and managers as it provides a means of performance measurement over time, in terms of the change in the percentage of quality timber products, the capital value of the standing forest, its ecological strength and the economic return from harvest operations.

While the results of sample stands in France are of interest, the real value in this book lies in the publication of both the concept and the protocol, which will facilitate a further expansion of the AFI network in different countries and different forest types.

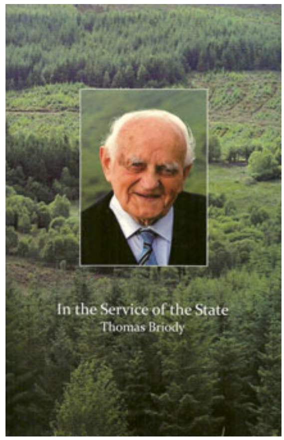
The book also provides general guidance in the practice of irregular forest management and a series of information sheets on different aspects of this, such as selective felling, permanent infrastructure, marketing, valuation and transforming plantations. This guidance is based on the experience gained in France to date and will require further development over time to suit Irish forest conditions as the AFI network develops further and starts to yield results in Ireland. The book is very well illustrated with photographs, drawings and graphs and also comes with a subtitled, 13 minute-long DVD which further illustrates the concepts discussed.

Management of Irregular Forests is an excellent read for both foresters and forest owners with an interest in silviculture and who have nagging questions about what the future holds for their forest and how it could be managed.

Patrick Purser, September 2013

In the Service of the State – The Memoirs of an Irish Forester

Thomas Briody. Choice Publishing & Book Services. 2012.
ISBN 978-1-909154-02-5. Pb 505.
€25



In the Service of the State by Tom Briody was launched by Donal Magner on 14th October 2012, two weeks before Tom's 99th birthday. It was a very happy occasion, attended by a large group of Tom's family and friends, at which the Society of Irish Foresters presented Tom with a specially minted medal to commemorate his being the sole surviving Foundation Member of the Society. Unfortunately, Tom Briody died shortly afterwards, on 23 November in his 100th year, and his obituary can be found elsewhere in this volume.

In the first volume of his memoirs, *The Road to Avondale* (2009), Tom recounted the story of his childhood in south-west Cavan, his path to forestry and his first few years as a forester. The second volume of his memoirs, *In the Service of the State*, takes up his story where *The Road to Avondale* left off. It tells of his transfer to the Slieve Blooms from Slievenamon, his marriage to Nora O'Hickey from Portlaw, and their life together up to Tom's retirement from forestry in early 1979. The story of their first home in the Slieve Blooms introduces a theme which is repeated throughout the book, i.e. the poor quality of foresters' housing. He describes the absence of the most basic of facilities, such as running water, an indoor toilet and proper cooking facilities. Electricity was rarely connected. Tom's descriptions give us a vivid impression of life during and after the Second World War where everything from bicycle tyres to fuel was scarce. All these problems were exacerbated by frequent transfers, which appeared to take no account of family or other domestic problems.

From the Slieve Blooms the family was transferred to Mount Bellew in east Galway; from there to Castleblayney, Co. Monaghan and thence to Foxford Forest in east Mayo. From Foxford he was transferred to Carrick-on-Suir. He was to spend the last 18 years of his forestry career in Carrick. Not surprisingly, Carrick looms large in this volume, but the trials and tribulations encountered at the other forest centres are also described in detail.

Carrick-on-Suir, at that time, was one of the largest transmission pole producing forests in the country. Tom describes the production process in fine detail and the significant economic contribution this enterprise made to forestry and to the country. Sadly it appears to be all in the past tense as Douglas fir is no longer an important component of our forests and all transmission poles are now imported.

Tom thought constantly of his forests. In the book he describes taking a half day leave to visit the dentist. The dentist had just numbed his gums when Tom, who had a view of the forest from the dentist's chair, saw a fire on the hill. He immediately abandoned the dentist's chair and headed straight for the fire, fully numbed! Tom's extraordinary dedication to duty is brilliantly captured in this vignette and many others throughout the book.

In the Service of State should have a wide appeal, and not just for people interested in forestry in pre-Coillte days. It tells a very human story, of the constant struggle to raise and educate a large family; of great personal sacrifice; of unbending attitudes in certain quarters of the Civil Service. Today's civil servants and politicians would do well to read this book and get an appreciation of the sacrifices that were made in developing Ireland's forest industry.

As I noted in the review of the first volume, the reader is left with the impression that Tom remained a positive and happy man despite all the ups and downs in life. He felt he achieved a lot "for his country" during his career as a forester. Both volumes of Tom's memoirs make a huge contribution to our knowledge of how this valuable natural resource took shape. We are indebted to Tom, and his son Dr Micheál Briody who edited both volumes, and completed such a wonderful job in making them accessible to a wider audience. In thanking Micheál, Tom describes how he carried him on his shoulders when he was a child, but that now Micheál was helping him to write his memoirs and fulfil the dreams of an old man.

The inclusion of a very comprehensive index helps one to navigate easily throughout the book. Let us hope that other foresters may now settle down with their pen or laptop to record their memoirs. Tom Briody has left us an excellent template.

John Mc Loughlin

John McLoughlin is Business Editor of the Society of Irish Foresters and Chairman of The Tree Register of Ireland.

Society of Irish Foresters Study Tour to Estonia
9–13 October 2012

The 2012 Study Tour visited Estonia – a small, sparsely populated country which has a forested area of 2.24 million ha (51% of the land area) and an annual harvest of almost 8 million m^3. Estonia is slightly more than half the size of Ireland and has a population of 1.3 million. Beginning in Tallinn, with an introductory lecture on forestry in Estonia, the tour group headed south to the university city of Tartu, stopping off at several well-managed forests en route. The group also visited a variety of wood-using industries, from the giant UPM-Kymmene plywood mill near Otepää to the Strauss family's small, wood-craft "factory" in the village of Avinurme, which relies on traditional wood-working skills of the villagers to produce an astonishing range of wooden toys, kitchen utensils and small furniture for export. In summary, this 69th Annual SIF Study Tour was a memorable one. We are deeply indebted to the hard working staff at Fest-Forest who organised, guided and educated us during our short visit to their beautiful country.

Overnight – Radisson BLU Hotel, Tallinn *Pat O'Sullivan, Tour Convenor*

Wednesday, 10th October 2012
As we headed out of Tallinn on the motorway towards St. Petersburg, we were joined on the coach by Felix Karthaus, our host from Fest Forest, who gave us an overview of the history of Estonia and the impact of this turbulent history on Estonian forestry. Forest cover was reduced to 30% of land area by the end of the 19th century. Estonia continued to be largely an agricultural country up to the mid 20th century. However, collective farms were established during the Soviet era (1941 to 1991) which resulted in large tracts of land being afforested. The agricultural reforms, which followed independence in 1991, resulted in 30% of agricultural land being removed from active use. Much of this land has since reverted to forestry with the result that 51% of the country is now forested. State forests account for 37% of the forest area.

The species distribution in Estonian forests is as follows: Scots pine (*Pinus sylvestris* L.; 32%), birch (*Betula* spp.; 31%), Norway spruce (*Picea abies* (L.) H.Karst.; 19%), grey alder (*Alnus incana* Mill.; 8.5%), aspen (*Populus tremula* L.; 5%), others (4.5%). Birch accounts for 80% of the forest cover in the east of the country and conifers constitute 60% of the species in the State-owned forests. The country is largely flat and low-lying. The highest point is a mere 365 m and average height above sea-level is only 50 m. The south of the country tends to have more gentle rolling hills than the north. Forest road building is rarely a problem and forest access is facilitated by an extensive network of dirt roads.

Our first stop was a 10 ha site of mixed forest comprised of birch, spruce and

Table 1: *Minimum age and height for the sanctioning of clearfells for the three most common species in Estonia.*

Species	Age (yrs)	Height (m)
Pine	90	28
Birch	60	26
Spruce	70	24

alder near Tooma, where harvesting was being carried out by guillotine. Our host, Toomas Kams, explained how the understory of scrub was first removed to give the harvesting operator a clear view of the base of the tree. This brush was removed to the roadside for green chipping. The chips were used for fuelling heating systems, such as centralised community-heating schemes. However, the harvesting of such brash is just about financially justifiable. The brash was sold for €5 to €6 per m^3. Clear felling is allowed based on age or height of the crop (Table 1), whichever comes first.

Up to 30 m^3 per ha for a single property or 3 m^3 per ha over several properties can be extracted without felling permission. On this site the basal area was 11 m^2 per ha which was considered low, whereas 20 m^2 per ha would be normal for Norway spruce across Estonia. Disease is not a major concern as mixed forests are healthier and disease, where it occurs, is regarded as part of the normal forest environment. The spruce bark beetle is not a particular problem. Pulp wood was being sold for €33–€38 m^{-3} (delivered). Commercial logs were making €70 m^{-3}, delivered. Log haulage costs approximately €5 m^{-3} per 80 km. There can be up to 15 different assortments on a site depending on the species mix. By law every lorry must have a timber movement docket to permit timber transportation.

Our second stop was at the E. Strauss AS Woodcraft Centre in the village of Avinurme (Figure 1). This company employs 20 people who produce a huge range of handcrafted wooden products for the sauna, kitchen and home. Most of the products are exported to Finland, but the company also exports to Sweden, Norway, Germany and Japan. Examples of production levels are 2,000 sauna buckets per month and 800 large fuel baskets per month. The plant is based on local, traditional, wood working skills. Lunch at the visitor centre consisted of solyanka, a thick, spicy traditional Estonian soup served with local rye breads.

Our third stop was on a restocked site in Ratsepa, which had been clearfelled over a number of years. Clearfell coups are capped at 7 ha and a maximum width of 100 m. In coniferous stands there must be five years between fellings and two years between fellings in broadleaved stands. After felling, a forest must be re-established within seven years of felling and there must be evidence of sufficient stocking within five years. Planting costs are considered high at €1,000 ha^{-1} and are avoided where possible. Thus, a "wait and see" approach is adopted in the hope that sufficient natural regeneration occurs. If a viable crop has not been established after seven years, the State has the right to plant a clearfelled area at the owner's expense.

Our final stop was in Fest-Forest's headquarters in Tartu. Here the manager

Figure 1: *Skilled local craft workers produce a wide range of wooden household items at the Strauss family's Woodcraft Centre in the village of Avinurme.*

presented a comprehensive account of its business model in Estonia. The basis of the client's investment was the current undervaluation of plantations in Estonia. Projections were based on likely growth in the value of land and timber rather than volume growth. Land values had fallen substantially in recent years to €500 ha^{-1}. The hierarchy of preferred species for investment purposes are Norway spruce, birch, aspen and alder. The wood-burning heating system used in the building was demonstrated to the group. It comprised two large water cylinders. The wood burner heated the water and this in turn heated the house. Sensors which recorded ambient temperatures both inside and outside the building controlled the distribution of heat. The system was highly efficient and used only 15 m^3 of timber per annum.

After checking into our hotel, the group was taken on a guided tour of the old city of Tartu, which is an important university city and is regarded as Estonia's intellectual and cultural hub. Students at the various universities and vocational colleges account for almost one third of its population. Our hotel, Hotel Antonius was directly opposite the imposing facade of the University of Tartu. During the tour of Tartu we saw the sculpture of the two Wilde's chatting – Oscar (1854–1900) and Eduard (1865–1933) (Figure 2). A most interesting day of professional and cultural education ended with dinner in the Gunpowder Cellar Restaurant.

Overnight – Hotel Antonius and Barclay Hotel, Tartu *Pacelli Breathnach*

Figure 2: *Oscar Wilde, Gerhardt Gallagher and Eduard Wilde*[1] *take a break at Vallikravi Street during our walking tour of Tartu's Old City. There is an identical statue at the corner of Shop/William Street in Galway. It was presented by the people of Tartu to Galway when Estonia joined the European Union on 1st May 2004.*

Thursday, 11th October 2012

On Thursday morning we were met by Professor Hardi Tullus of the Department of Silviculture, Estonian Institute of Forestry and Rural Engineering in Tartu, who brought us to see a research trial of hybrid aspen (*Populus tremulus* L. × P. *tremuloides* Michx) which was planted on abandoned farmland. During our short bus trip to the experimental plots, we were treated to a condensed history of forestry education in Estonia and the pivotal role of Tartu University in forestry education and research. These experimental plots were our first introduction to plantation forestry in Estonia and Professor Tullus pointed out that continental forestry is rapidly moving towards plantation forestry in its quest for ever greater crop yields. The site had been ploughed and planted with hybrid aspen at a stocking level of 1,300 ha^{-1} with the following objectives:

- To monitor changes in chemical and physical soil properties;
- To study successional changes in the understory vegetation (vascular plants and bryophytes);

[1] Eduard Wilde (1865–1933) was a revered Estonian writer and diplomat. His better known works include *The War in Mahtra and The Milkman from Mäeküla.* In addition to being a prolific writer he was an outspoken critic of Tsarist rule and of the German land-owning class in Estonia. When the first Estonian Republic was established in 1919, he served as its ambassador in Berlin for several years.

- To estimate biomass production, allocation concentration and content (as well as calorific value) of major minerals, nutrients, cellulose, hemi-cellulose and lignin;
- To analyse foliar nutrient concentrations in order to identify and evaluate nutritional conditions of forests and potential limiting growth factors.

The first assessment of the understory plant-cover was carried out when the plantation was six years-old. In total, 33 vascular plant and five bryophyte species were found on four vegetation plots. The coverage of the field layer was 71% and bryophytes covered 4%. The second survey was undertaken when the plantation was 12 years-old. Altogether, 35 vascular plant species were found, the coverage had decreased to 25%. The coverage of the bryophyte layer had increased to 6%.

We then returned to Tartu and headed south to Otepää where we saw some low hills for the first time since coming to Estonia. In Otepää we visited the huge plywood mill owned by UPM-Kymmene and Otepää AS. We were brought on a tour of the mill by Ando Jukk, the mill manager. This is the only plywood mill in Estonia and the second largest plywood maker in the Baltic countries. A total of 195 people are employed in the mill and the UPM group employs 23,000 people globally. Our first impression of the mill was of a vast log-yard of veneer quality birch logs (Figure 3) – not a familiar sight for Irish foresters! Birch logs for plywood are procured from local forests within a maximum haulage distance of 100 km. Between 125,000 m^3 and 130,000 m^3 of logs are required annually. In addition to standard plywood, the mill also processes top quality WISA plywood for use in the automotive, transport, furniture and construction industries. The expansion and modernisation of production has improved the manufacturing efficiency of the mill. Annual base plywood production capacity has increased to 50,000 m^3. A plywood

Figure 3: *High quality birch logs at UPM-Kymmene's plywood mill at Otepaa.*

coating line was added to the mill at the beginning of 2009. Just over 90% of the mill's production is exported, mainly to central Europe. Otepää's location in the Baltic rim means that deliveries can reach its main customers in the northern parts of central Europe within a day. This year the mill was ranked the third-best company in Estonia by the Estonian business paper, *Äripäev*.

After another traditional lunch at the panoramic Nuustaku, it was onwards again to the Vulga State forests which are managed by RMK (the Estonian state forest management organisation), where our host was Risto Sepp. RMK manages 1.12 million ha or approx 40% of all the forests of Estonia. RMK has achieved both FSC and PEFC certification on the timber produce from its forest estate. It has a target of 15% biodiversity. The site we visited was in a National Park where a non-commercial thinning had occurred (Figure 4). It was termed a "sanitary thinning", in which only poor quality Norway spruce, deadwood and stems which were damaged by moose through bark stripping are removed, leaving the better Scots pine to grow on. The thinning volume was approximately 20 m^3 ha^{-1} and was being carried out using a John Deere 770D. This was the crop's third thinning; the crop will not be clearfelled as this is a protected area.

At the next site we were shown a good example of a mesotrophic pine forest i.e. native forests where "zero intervention" was the management regime. These native forest areas are identified clearly with large signs along the roadside. Finally, Risto showed us a nearby site from which the scrub had been removed and stacked for green chipping for pellet manufacture. The site was semi-natural grassland that is

Figure 4: *A fine stand of Scots pine remained after the sanitary thinning had been carried out.*

Figure 5: *Late autumn colours are reflected in one of the many small lakes at Pilkuse Jarv recreation area.*

EU designated for the protection of the corncrake, buzzard and eagle. The plan is to manage it as grassland and to lease it on an annual basis to farmers. The brash, which was harvested and stacked, was not in demand this year and the grazing rights may not be availed of either. There was EU funding for this project and the group questioned if it was sustainable without such support.

The final stop was a recreation site in Pilkuse jarv, a beautiful lake in a woodland setting (Figure 5). This site, which provides car-parking for 10 cars, a jetty and a log cabin/sauna had 12,000 visitors last year. On our way back to Tartu, we stopped briefly at the new Tehvandi Ski Jumping Centre of Excellence on the outskirts of Otepää where athletes come to train for competitions. Otepää is the home of Estonian ski jumping and both the current men's and women's Olympic champions are from this area.

We ended the day with a specially arranged performance by a local choir in Tartu's historic Town Hall. Several of the Fest-Forest foresters are members of this choir, which treated us to a memorable performance of traditional songs of love, loss and of days spent working in the forest. Our President, John McLoughlin replied eloquently "as Gaeilge" and thanked the choir for its wonderful performance in this grand setting.

Overnight – Hotel Antonius and Barclay Hotel, Tartu *Kieran Moloney*

Friday, 12th October 2012

Our first stop was an area of abandoned farmland close to Tartu, where we were introduced to Joel Peetsu who works for Est Kinnisvara OV, a property development company. Here the company has 13 sites for sale with planning permission for one house on each plot. The plots incorporated agricultural and forested land and varied in size from 2 to 3 ha. Est Kinnisvara OV builds the service roads, but the purchaser must install the sewerage, electricity and water, which commonly cost about €9,000 for all three services. The site cost varies from €10,000 to €12,000, depending on the location and the quality of the forest being sold with the land. The cost of building an average-sized house here was approximately €80,000. The purchasers of these plots tended to be from the area and working in Tartu. Est Kinnisvara OV sourced its plots exclusively from Fest-Forest and has built up a portfolio of 150 plots throughout Estonia in recent years. Some of their more remote rural plots are sold as holiday home sites. The rate of agricultural land-tax is €4 to €5 ha^{-1} per year, whereas a house site incurs a tax of €20 ha^{-1} per year.

We made a brief stop outside the Stora Enso Eesti Imavere sawmill where Tanu, our guide for the day explained that this is the largest saw-mill in the country and was built in 1995. It takes in 600,000 m^3 per annum of pine and spruce timber, but has the capacity to process 700,000 m^3. The plant employs 300 staff. There are four separate mills on the site; one is a standard sawmill, one makes glulam beams for use for windows and doors, one makes glulam beams for house building in Japan, and a final one produces chips for paper manufacture. Stora Enso purchases its timber supplies from both RMK (the State Forest Service) and from Fest-Forest. They take in logs with a minimum diameter of 11 cm and lengths from 3.4 to 6.1 m. Current prices are €72 m^{-3} at millgate for pine of 25 cm diameter, and from €65 to €68 m^{-3} at millgate for 30–32 cm diameter spruce logs. More than 90% of production is exported, mainly to Germany. Due to the unseasonably wet summer this year, log supply was down significantly.

Our final stop of the day was a visit to the Balcas Eesti's sawmill outside Tallinn. The mill manager, Inderec, explained that the Balcas involvement began here in 1995. The mill is a second-hand plant bought from Sweden. It has no electronic scanners and is therefore quite labour intensive. In 2008, the mill processed 180,000 m^3 of timber, but they are now processing only 60,000 m^3 per annum. The workforce has also decreased from 200 to only 34 at present. The two main reasons for this decline are the high price of Russian logs and the difficult export market for sawn timber. Currently, Russian logs cost €85 m^{-3} at dockside plus an additional €10 m^{-3} to load and transport the logs to the mill; this is why Balcas is not buying any of this timber. Instead, they source their spruce and pine logs from RMK (50%) and private growers (50%), and their current millgate price is €65 m^{-3} underbark. He has a preference for spruce logs as this is the species most suited to market requirements. The average haulage distance to the mill is 90 km.

Balcas Eesti has long-term purchase agreements with RMK, which are reviewed each year. Their log supply has also been negatively affected by the very wet summer this year. We were then shown around the plant and saw the log diameter grading system which has 30 separate bins, the sawmilling section, the area where stress grading is carried out (grades C12 and C16 and DR 26 for roof trusses), and the boiler which generates 2 MW of power from sawdust and is capable of supplying the total energy requirements of the mill, including its eight drying kilns. All of the sawn timber is exported either to the UK or Ireland. All their chips are exported to Finland for paper manufacture, bark is also sold to Finland for the horticulture industry and the sawdust is sold to local pellet and chip-board manufacturers.

Overnight – Radisson BLU Hotel, Tallinn *Eugene Griffin*

Saturday, 13th October 2012

The party assembled early on Saturday morning for a walking tour of Tallinn's old city (Figure 6). This would be the final stage of a tour which revealed Estonia as a multi-faceted country with a rich history and a diverse culture rooted in centuries-old traditions.

Tallinn, the oldest capital city in northern Europe, is an old hanseatic city with well-preserved medieval walls. Large sections of these city walls, originally 2.4 km in length and supported by 26 defensive towers, still stand today. The Old Town area is now a UNESCO World Heritage Site. The focal point of Tallinn is the Old Town Square which is dominated by a late Gothic town-hall dating back to the early thirteenth century. The world's first Christmas tree was erected in the Old Town Square in 1441. Toompea Hill is another important landmark and is the site of Estonia's government buildings and Toompea Castle, the seat of Estonia's Parliament.

Figure 6: *A rooftop view of the Old City area of Tallinn.*

Tallinn has always had a close connection to sea trade and maritime affairs since it's port does not freeze during the long Baltic winter. The spire of St. Olaf's Church, the tallest church in Estonia, was a welcome first sight of land for returning sailors over the centuries. In modern times the aquatic events of the 1980 Moscow Olympic Games were held at Tallinn.

In recent years the Rotermann Quarter, an area of abandoned industrial buildings in the heart of Tallinn, has been developed in line with the principles of modern urban planning and has attracted much praise for the admirable quality of its contemporary architecture. The careful merging of medieval and modern buildings has produced a very pleasant cityscape.

Frank Nugent

Tour Participants (32)

Pacelli Breathnach, Michael Bulfin, Richard Clear, Jim Crowley, Declan Egan, PJ Fitzpatrick, Jerry Fleming, Gerhardt Gallagher, Tony Gallinagh, Eugene Griffin, John Guinan, Marcus Hanbidge, George Hipwell, Mark Hogan, Tim Hynes, Kevin Kenny, Noel Kiernan, Eugene McKenna, Willie McKenna, John Mc Loughlin, Kieran Moloney, Liam Murphy, Frank Nugent, Benny O'Brien, Michael O'Brien, Paddy O'Kelly, Tim O'Regan, Pat O'Sullivan, Gerry Riordan, Richard Whelan, Trevor Wilson, Izabela Witkowska.

Obituaries

P.J. Cotter
1939 – 2012

News of the death of P.J. Cotter, after a very short illness, came as a great surprise and shock to those who knew him, especially his family and his forestry friends. A big, quiet man, P.J. seemed indestructible, he left us too soon and we will miss him.

A native of Kinsale, he entered forestry in 1958 having spent a year studying at Darrara Agricultural College. In Kinnitty Castle Forestry College he excelled in the practical application of forestry practice. He then spent two years studying at Shelton Abbey Forestry College before graduating in 1960.

His first appointments as an Assistant Forester were to Clonaslee, Kinnitty, and Forth Forests. He then transferred to Clonegal nursery where he met his wife, Anne (nee Hendrick). In 1967, P.J. was appointed Forester-in-Charge at Kilmacrennan Forest, Co. Donegal and in 1974, when he was transferred to manage Camolin Forest, Co. Wexford, he settled in Ferns where he would spend the rest of his life. Following the setting up of Coillte, P.J. was appointed Manager of Camolin Nursery in 1990 and it was in this role that his great skills of organisation and routine came into their own. This was a time of great expansion and development and meeting the plant requirements for this expansion was a huge challenge but one which P.J. rose to with great enthusiasm. He availed of Coillte's Voluntary Parting Scheme on 30th September 2002 after 44 years of exemplary service.

P.J. had a great passion for sport. He was a die-hard supporter of his native Cork and also of Manchester United. He was a member of Courtown Golf Club for more than 30 years. He was a loyal member and Past President of the Eastern Forestry Golfing Society, rarely if ever missing an outing. He played Bridge with his great friend Jim Kennedy every week and kept his mind active with Sudoku. He also followed the hunt using his preferred method of transport – his car! He had a quiet sense of fun and was a member of a syndicate that put a greyhound by the name of "Coillte Six" in training. He was a loyal member of the Society of Irish Foresters and the Coillte Branch of IMPACT.

P.J. and Anne were married in July 1968 and they had four children. He was devastated when Anne died suddenly in 1996. Above all P.J. was a reliable and loyal friend and a fair-minded man, who loved his family.

To his daughter Fiona, sons Liam, Colm and Ciaran, six grand children, brothers Liam and Jimmy and sisters Noranne and Sheila, we extend our sincere sympathy.

Ar dheis Dé go raibh a anam.

Michael Doyle

Jerome Dufficy
1946 – 2012

Jerome Dufficy passed away on 20th August 2012 after a long illness that, heroically assisted by his family, he bore with incredible dignity, fortitude, and good humour. In early 2007, he was stricken with motor neuron disease which caused a slow deterioration of his muscles leading to a gradual loss of mobility and of his ability to communicate. The strain of this was all the greater because Jerome had been such an active and sociable person in his family, social and professional life.

Jerome was born into a farming family in Tulsk, Co. Roscommon in 1946. He won a scholarship to Summerhill College in Sligo, and from there he went to University College Dublin where he studied forestry, graduating in 1970 with an honours degree. He immediately joined the Forest Service where he was assigned to Land Acquisition in the north-west, based in Sligo and for a time in Letterkenny. His courtesy and his humorous personality together with his farming background made him "a natural" at negotiating land deals; farmers and other land vendors all enjoyed doing business with him. Among his proudest achievements in this phase of his career was the acquisition of many of the lands now supporting successful plantations. He was then transferred to the Timber Marketing section, a post he held at the establishment of Coillte in 1989. This new challenge gave him the opportunity to display his inventive and flexible character. His independent and questioning mind brought clarity and transparency to whatever task was in hand, and he played a major role in the introduction of several important company-wide innovations. As with the land vendors, his easy manner with both timber customers and Coillte colleagues allowed him to introduce change with the minimum of fuss.

Jerome was a GAA enthusiast all his life. In his youth he won an All-Ireland under-21 Football medal with Roscommon in 1966 and later was everpresent on the UCD team playing in many Sigerson campaigns. In maturity he was an active member of Rosses Point GAA club and even used his land acquisition skills to source a playing pitch from a neighbouring farmer. He later was a key figure in bringing about the merger of Rosses Point Club with Drumcliffe where his son Kevin is now a leading player. He was equally active in Rosses Point Golf Club where, as well as being a gifted and competitive player, he was Chairman of the Management Committee and of the Greens Committee. On the Greens Committee, he had a lasting effect on the course when he created a famous bunker, the end of many a potentially good round, now referred to as Jerome's Grave!

Jerome was an easy going, sympathetic and loyal person who enjoyed company. As a student he was always ready to start a sing-song accompanied by his trusty guitar. He was well known in his local community in Sligo as a choir singer, community worker, and good neighbour. He built up a lot of very close friends through his life and was always ready to help whenever needed, for example using his DIY expertise. Above all else though, Jerome was a family man. He was devoted to his wife Máire and their children and grandchildren. In his illness, Jerome was supported in an incredible manner by Máire and all the family who displayed many of the characteristics of Jerome himself in their selfless caring. It was an elevating experience to see how Jerome accepted the support of his family and friends in a most dignified way that could only be imagined by others. He did not let his illness prevent him from enjoying company as was shown by the way he clearly loved having a coffee in the golf club with his pals. In latter times, while he was restricted to being a listener, he invariably displayed absolute interest and made all feel comfortable in spite of his severe restriction of mobility and speech. He missed nothing, and if there was any bit of *divilment* to be had, one could see him roaring laughing just with his eyes!

To Máire and to his family Colm, Sarah, Paula, Kevin and Anna, grandchildren, his brothers and sisters and all his extended family, we extend our deepest sympathy.

Dermot O'Brien and Paul Clinch

Tom Briody
1913 – 2012

The sight of two aeroplanes flying over the townland of Callanagh near Mullahoran was Tom Briody's earliest recollection of his Co. Cavan childhood. The planes swooped so low that he could "actually see the occupants". The terror stricken three-year-old recalled his father shouting, "the Germans have arrived." This event occurred in the spring of 1917, when World War I was still raging. The incident, recalled by Tom in the opening lines of the first volume of his memoirs, is the beginning of a remarkable story; all the more remarkable since he only began recording it as he approached his 90th year. There is something heroic about this late-conceived project, which gave him a new energy when a lesser mortal might have succumbed, especially after his beloved wife Nora died in November 2000.

His memoirs began with sketches of family life during his youth in Mullahoran, Co. Cavan but, encouraged by his son Michéal, a story began to unfold that is an indispensable element of Ireland's 20th century forestry narrative. Like many foresters, he came from a farming background and this aspect of his childhood and early teens dominated the early section of his first volume *The Road to Avondale: The Memoirs of an Irish Forester.* It is a study of survival and resourcefulness especially by his mother, Annie, who was major influence in his life. His background influenced his decision to pursue a career in agriculture. He entered Ballyhaise Agricultural College in 1936 followed by the Albert College, Glasnevin in 1937. He finally decided on a career in forestry as the "road to horticulture had become bleak".

A common theme among foresters of his generation was a need to justify their decision to take up forestry, especially to their families who were frequently unsympathetic towards the profession. His mother's blessing was important to him as he explains in *The Road to Avondale.* "She it was who had initially helped me to identify the various farm and bog weeds. She had taught me the magic of seed sowing. She it was who had taught me the wizardry of matching the various colours in the flower garden." He won his mother around and entered the forestry school in Avondale in 1937 and qualified in 1940. After qualifying, he was appointed as forest foreman in Kilsheelan, Co. Tipperary and forester-in-charge in Slievenamon, where he operated the Emergency Fuel Scheme during the Second World War.

In the Service of the State, the second volume of his memoirs, several facets of his life are combined, especially his role as a forester along with insights to local and national events. It also recalls his family life and circumstances. In this regard the book is a tribute to his wife Nora and how she coped with life as a forester's wife, which involved frequent transfers at short notice when the family criss-crossed the country, often living in conditions, which were poor even for the time. He served as forester in all four provinces, from Slievenamon to Clonaslee and Mountbellew and on to Castleblaney and Foxford, before his final destination in Carrick-on-Suir.

Tom was acknowledged for his expertise in establishing and managing forests. He was one of the founding members of the Society of Irish Foresters in September 1942. His lifelong commitment to the profession of forestry was properly and formally acknowledged in 2009 when he was conferred with Honorary Membership of the Society.

His approach to forest protection, especially to fire control in high risk forests such as Foxford, was an exercise in total commitment to forestry. His approach to timber production and marketing, especially during "The Emergency" when timber was in short supply, was a master class in resourcefulness and innovation.

He was also a humane forester and possessed a deep understanding and empathy with forest workers and the numerous assistant foresters who worked with him over the years. He was at ease in their company and even with the officials who, at times, made life difficult for him and his family with their overzealous approach to transferring foresters. In this regard, his outlook was well captured by his son Michéal when he paid the final tribute to Tom at his funeral Mass in Carrick-on-Suir: "My father forgave those who hurt him and did not hold grudges for very long."

Sadly, Tom passed away on 23rd November 2012 in his 100th year, and two weeks after the launch of the second volume of his memoirs, which I had the honour to launch. The forestry community and the State are indebted to him for his achievements over the years, not least for recording what it was like to be a forester at the birth of Irish forestry and to shape its development for much of the 20th century. His memoirs have brought this important period in Irish forestry alive to a whole new generation.

Predeceased by his wife Nora (nee O'Hickey), daughter Geraldine and son Eamonn, he is survived by his daughters Joan, Anne and Máire, and sons Tomás, Mattie and Michéal to whom we offer our deepest sympathy.

Beannacht Dé leis agus le hanamacha na marbh.

Donal Magner

Dr. Jack Durand
1929 – 2012

The death on 16th December of Dr. Jack Durand at the age of 83 is an inestimable loss, not only to his wife, family and relatives, but also to a wide circle of friends and colleagues worldwide as well as in Ireland. The loss is not limited to people, but also to forestry as a commercial enterprise; as an environmental necessity and as an amenity to be enjoyed by young and old.

He was born in Waterford city, son of Pierce and Mary (nee Connolly) and attended school with the Christian Brothers in that city. In his youth, Jack was a keen sportsman with a county medal for hurling with his native Waterford and also medals for rowing with two universities, UCC and TCD. He was a keen fisherman. In 1950 Jack graduated from UCC with a BE degree in Civil Engineering and worked for a short time with various local authorities in Ireland and the OPW (Arterial Drainage), before going to Canada where he worked in British Colombia designing forest roads. The experience and environment awoke in him the desire to study forestry. In today's world, change of career is common but when Jack made his decision it was most unusual and required courage and conviction to relinquish a permanent job and become a student once again.

In 1960 he graduated from TCD with a First Class Honours degree in Forestry. This was an important year for him as he also met and married Sheila. He entered the State forest service in January 1961. In 1964 he was promoted in charge of the newly formed Amenity Section which dealt with recreation and the "Open Forest" policy. Shortly afterwards he went to Duke University, North Carolina, to study best practice in US forest and parks departments. In 1969, Jack was awarded a PhD by the National University of Ireland for his thesis "The evolution of State Forestry in Ireland".

In 1972 Dr. Durand was appointed Director of the John F. Kennedy Arboretum near New Ross replacing another notable forester, the late Tony Hanan (1923-1972). He was Director there until 1978 when he was transferred to Dublin where he remained in charge of amenity and private forestry until he retired in 1988. Jack took up the challenge of establishing the new arboretum with characteristic verve. In particular, his care for the fledgling plant collections was evident from harmonised extensions to the shelter belts. On ground shaped to simulate hills and valleys, he planned the display of 400 species and varieties, grouped by genus. His love of plants was reflected by his interest in other collections. He was especially fond of the nearby Woodstock, Inistioge. His advice was sought by Forest Management when encroaching scrub was being cleared from the arboretum. He delighted in the rediscovery and measurement of so many fine specimens, especially the champion *Sequoia sempervirens*, central to this collection.

Over the years Jack acted variously as Business Editor of *Irish Forestry* and as

Treasurer and Vice-President of the Society. He also published articles in the Journal "Forest haulage roads in British Columbia" (Vol. XX, No. 1, 1963) and "Building a Resource - 50 years of Irish Forestry" (Vol. 49, No.s 1&2, 1992). The latter article was based on The Augustine Henry Memorial Lecture he gave at UCD in 1992 where he marked the 50-year anniversary of the founding of the Society, as well as honouring the contribution of Augustine Henry to forestry in Ireland –in particular for his publication of *The Trees of Great Britain and Ireland.* He also contributed on amenity matters to "*The Forests of Ireland*" which was edited by H.M. FitzPatrick in 1965. Other publications "*Ash for Hurleys and Profit*" initially published by Trees for Ireland and more recently by the Tree Council of Ireland. Together with Donal Magner he wrote a booklet on "*The Trees of All Hallows*".

Jack was also active in the Tree Council of Ireland, Trees for Ireland, An Taisce and anywhere that he could promote an interest in silviculture. His enthusiasm for trees and forestry was inspirational. He was a great admirer of the famous Scottish plant collector David Douglas (1799- 1834). While on one of his many global trips, Jack arranged for a memorial to David Douglas to be erected in Hawaii where Douglas died. In 2009, the Forestry Commission arranged a commemoration of David Douglas at Pitlochry, Scotland. Jack organised a small group of forestry colleagues to attend this function. The following day he brought the group to the Botanic Gardens at Edinburgh and afterwards to Glasgow to witness Celtic in action. Forest utilization at its best!!

After retirement from the state service, Jack established himself as a private consultant in arboreal matters and took an active part in local community projects. In later years he and his wife Sheila became world travellers. Postcards to arboricultural friends depicting some obscure species would carry the message "Doubtless you recognise this tree immediately"!

Jack was generous with his knowledge. His integrity and erudition were combined with modesty. If he disagreed, he would express his views firmly and with courtesy and if the occasion allowed, with humour. He was a committed Christian and his religion was very important to him. The Society of Irish Foresters has elected twenty three Honorary Members for their outstanding contributions to the aims of the Society. Dr Durand was delighted to become the twenty fourth Honorary Member in November 2012.

Our deepest sympathy goes to his beloved and loving wife Sheila and his sons and daughters, Lonan, Sheila, Paul, Ciara and Marian. Also to all fourteen grandchildren and his brother Michael and indeed to all who mourn the loss of a good friend and colleague.

Go dtuga Dia suaimhneas síoraí dá anam dílis.

Dr. Neil Murray

Stefan Otto Schmeltz
1931 – 2013

Stefan Schmeltz died, after a long illness, on 19th February 2013. He was born in Vienna in 1931, the only child of Hans and Elisabeth Schmeltz. Stefan left Vienna shortly after Adolf Hitler annexed Austria in March, 1938. Although his departure was hasty and those distant memories faded, he could still recall vividly how his school had to replace all religious pictures and icons with images of the Führer and swastika. Each morning, instead of prayers the pupils had to salute these new emblems. He remembered crossing Europe by train and arriving in Southampton, whence he was brought to Dundalk to be fostered by John and Mary Hamill. Stefan always referred to Dundalk as home, the Hamills as his family and Mary Hamill as mother. His own mother moved to America and his father to Argentina where he died at a relatively young age. Sadly, Stefan never saw his father again and he met his mother only twice - once when she came to Ireland and again later when he travelled to America with his wife Phil.

Stefan received his early education in Dromiskin National School, near Dundalk, Co Louth, while his secondary education was completed at CBS Dundalk and Rockwell College, Cashel, Co Tipperary. He also completed an extra mural Diploma in Social Science at UCD in 1971. It is worth noting that Stefan, who could speak only German when he arrived in Ireland, quickly became proficient in three new languages – English, Irish and Latin. He entered Avondale Forestry School in 1951 and completed his forestry course in 1954. He spent his practical year in Burncourt, Co. Tipperary and in Dungarvan and Cappoquin Forests in Co. Waterford. Stefan joined the Society of Irish Foresters in April, 1952 and remained a life-long member.

His first assignment as a forester was at Avonmore Workshop, where he helped develop the prototype of the timber-clad forester's house. Between 1955 and 1958, he served at Avoca (where P.J. Morrissey was the Forester-in-Charge), Aughrim and Rathdrum Forests in Co. Wicklow. In June 1959, Stefan was promoted to the grade of Forester-in-Charge of the new forest at Edenderry, Co. Offaly. Under his stewardship Edenderry forest expanded hugely - from a mere 200 ha in 1959 to 1,550 ha when he retired in 1990. It was in Edenderry that Stefan met his future wife, Philomena O'Kelly, whom he married in August 1960.

Stefan's love of forestry was evident to all but he had a particular fondness for broadleaf trees. He was particularly proud of the extensive oak and beech plantations he nurtured at Rahin and Killinthomas woods. He valued these plantations so highly that he rarely allowed anyone other than himself to carry out thinning and tending. Stefan tended his beloved broadleaves with great care and the wonderful oak and beech plantations that remain to this day at Rahin and Killinthomas are testament to his careful stewardship.

Although he adapted very well to his adoptive country, Stefan could scarcely be described as a typical midlands forester. In his initial interactions with people he was somewhat distant and in conversation his replies were generally monosyllabic. He was a man of few words - his philosophy appeared to be - why use three words when two would do! Indeed his trademark signature (*SOS* for Stefan Otto Schmeltz) was further evidence of his verbal economy as was his approach to memo-writing. A "Stefan" memo rarely exceeded three sentences, yet it always delivered a clear and concise message ….. no matter which of his newly acquired languages it was written in!

However, as one got to know Stefan, one discovered a man of the highest integrity, who was caring, kind, and compassionate. His wife Phil, who predeceased Stefan, was renowned in forestry circles for the restorative qualities of her "mug of soup" which helped to revive many a tired and hungry forester on a cold winter's day. After settling in Edenderry in 1960, Stefan became an active member of the community. For many years he was a member of the local Golf Club and he and Phil shared a keen interest in Bridge which they played weekly with the local club.

Stefan was a truly remarkable man. He overcame trauma, upheaval and separation to succeed against the odds in developing a comfortable and secure life in his adopted country. To the Hamill family of Dundalk, who were indeed his family, and to his in-laws, the O'Kelly family of Edenderry, we offer our sincere sympathy.

Möge er in Frieden ruhen.

Aiden McGuire

John Ernest Johnston
1923 – 2013

It was with great sadness that the forestry fraternity learned of Ernest Johnston's passing on 2 July after a brief illness, having celebrated his 90th birthday one month earlier.

Ernest was born on 2 June 1923 in Rathkeale, Co Limerick to the Rev. James Johnston, a Methodist Minister, and Mrs Eva Mary Johnston (nee Hewitt).

His father's Ministry entailed frequent transfers throughout the country. Thus, while living in Belcoo Manse, he received his primary education at the Model School, Enniskillen. His secondary education was at the Royal School, Cavan.

He read Arts and Forestry at the University of Dublin (Trinity College), graduating in 1948. While a student at Trinity he completed his practical assignments at Emo and Aughrim Forests.

His professional career in forestry began as a Forester and Farm Manager on the Lough Eske Estate in Donegal and in 1950 he took up a post as Forester at Johnstown Castle, Co Wexford.

He began his career in the State Service in 1952, in what was then the Forestry Division of the Department of Lands, when he was appointed Acquisition Inspector in Sligo, a position he held until he was promoted to Divisional Inspector in Sligo in 1967. He remained there until he was promoted Senior Inspector at Headquarters in Dublin in July 1979. As Senior Inspector he was responsible at various stages for Acquisition, Amenity, Conservation and Nurseries before finally taking over Management North and Education. He retired in 1988 at the age of 65 and returned to his beloved Sligo to spend 25 happy years of retirement.

Ernest was a thoroughgoing gentleman, outstandingly erudite, remarkably polite and always willing to provide a listening ear and in return providing invaluable advice.

He was active in the Society of Irish Foresters. He led the Donegal/Tyrone Study Tour in 1978, outlining clear silvicultural options for the many crops visited. He also led many forest walks in Sligo. He published an article entitled "Corcashel Plantation, Co. Cavan" in Irish Forestry, Vol. X1V, No. 2, Winter 1957, pp 122–123. This plantation was then owned by Cavan County Council**.** Recently, he very kindly donated his fine collection of 'Irish Forestry' journals to the Society.

He is survived by his wife Irene, son James, daughter Anne, daughter-in-law Jane and his grandson Harry, to all of whom we offer our deepest sympathies. He was predeceased by his brother, Vivian.

Bill Dallas

Cecil Kilpatrick
1921 – 2013

Cecil Stephen Kilpatrick passed away peacefully at home aged 92 on 8th October, 2013 surrounded by his family who had cared for him tenderly over recent years. His funeral was held in St James's Church, Lower Kilwarlin, close to his home near Hillsborough, Co. Down.

Cecil was born at Portballintrae, Co. Antrim on the 14th April, 1921. His father was a teacher and he had a brother and two sisters. He attended the local schools and then as a teenager expressed an interest in a career in the army. As a result his father decided in 1937 to send him as a boarder to Campbell College in Belfast as it had a well known Combined Cadet Force.

Following the outbreak of war in 1939, Cecil joined the Royal Engineers and served in India and Burma. At the end of the war in 1945 he retired from the army with the rank of Major.

He then decided on a career in forestry. With an ex-service training grant he enrolled on a forestry degree course at Edinburgh University and graduated three years later in 1949. He obviously did not spend all his time on studies as he met a fellow student, June Thomson, who was to become his wife. On hearing of their engagement, June's mother earnestly enquired "Was there not a man in the whole of Scotland good enough for you?"

Shortly after graduation Cecil was recruited in December, 1949 to the Forest Service in Northern Ireland and was posted in 1950 as District Forest Officer to Co. Down and Armagh, based in Newcastle. He was closely involved in the development of the first Forest Park in Northern Ireland at Tollymore, which opened on 2nd June, 1955. Prior to this, virtually all forests were out of bounds to the public except on business. During the 1960s a further four forest parks were opened at Gortin Glen, Castlewellan, Gosford and Drum Manor. These were all extremely popular with the public.

In 1957 Cecil was promoted and transferred to Headquarters in Belfast as Deputy Chief Forest Officer. Just four years later, on 16th September 1961, Hurricane Debbie devastated 8% of state forests over 20 years of age. This created an increase in the workload of staff at all levels. In his new post Cecil had responsibility for Private Forestry, Conservation and Wildlife Management in the Forest Service. He was keen to ensure that the forests were managed for multiple uses - not only for timber but for recreation, conservation, wildlife and education. He introduced District Conservation Committees and liaised with voluntary conservation organisations and the Department of the Environment to improve conservation within forests. Areas of significant conservation value were designated either as Forest or National Nature Reserves. In 1971 the Forest Service celebrated the planting of its 100,000th acre. Cecil had a particular interest in wildlife management within forests and he was influential in the development of the Irish Deer Society. He served as its President in 1981 and 1982.

Cecil was promoted to Chief Forest Officer in 1977 and served in this post with distinction until his retirement in 1983. It was always a pleasure to work with him and he valued and encouraged his staff at all levels. With the election of Mrs Thatcher's Conservative Government in 1979, another cold wind struck the Forest Service! The future emphasis was to be on commercial forestry and a progressive reduction in spending of 5% per annum. An incentive scheme was introduced for the industrial workers and a reduction in the technical and professional staff. Cecil's six year period as Chief Forest Officer was not a bed of roses!

In 1985, a conference was held to celebrate 75 years of State forestry. Cecil was invited back to give a lecture on the history of forestry during this period and he held his large audience enthralled. This lecture was in fact the summary of a book written by Cecil and published by the Forest Service in 1987. The title of the book was '*Northern Ireland Forest Service – A History.'* Unfortunately, this book is currently out of print.

Cecil was the first member of the Forest Service of Northern Ireland staff to join the Society of Irish Foresters and served as its President in 1966 and 1967. In this latter capacity he once received a letter from India addressed to him as "President of Ireland"! Later, in 1992, he was awarded Honorary Membership of the Society.

Cecil was a man with wide interests which included Irish history, gardening, wine making and bee keeping. He was also a great supporter of St. James's Parish Church where he served for many years as Treasurer and Church Warden. Above all, he was a very devoted family man. He and June were married for 64 years and we extend our deepest sympathy to her, to their daughters Wendy, Elizabeth Anne, Gillian, Christine and Freya and to their son Stephen.

Bill Wright