IRISH FORESTRY

JOURNAL OF THE SOCIETY OF IRISH FORESTERS

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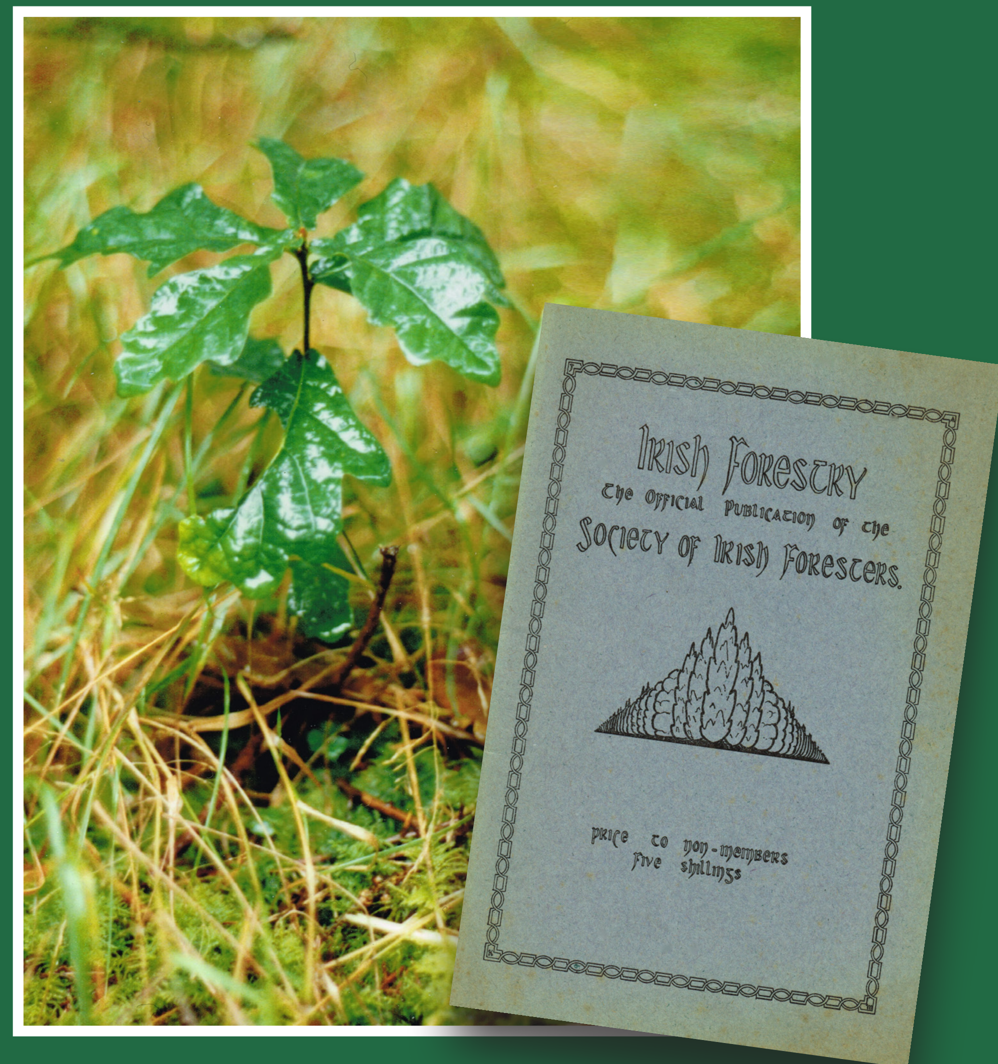

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The Society of Irish Foresters

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Mission Statement

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

Objectives

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

Submissions of articles to Irish Forestry

Submissions

1. Original material only, unpublished elsewhere, will be considered for publication in *Irish Forestry*. Where material has been submitted for publication elsewhere, authors must indicate the journal and the date of submission.
2. All submissions must be in MS Word, submitted electronically to the Editor, *Irish Forestry* at info@soif.ie (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.
4. On submission, authors should indicate up to three potential referees for their paper (providing full contact details for each referee). Choice of peer reviewer rests in all cases with the Editor.
5. Peer reviews will be communicated to authors by the Editor. Changes suggested by the reviewer must be considered and responded to. It is expected that co-authors should be informed of, and in agreement with, such changes and responses. The decision to publish will be taken by the Editor, whose decision is final.
6. Guidelines for authors on *Irish Forestry* house style and layout can be downloaded as an MS Word template from http://societyofirishforesters.ie/lrishForestry.

Front cover: Oak regeneration in a Sitka spruce stand. Inset: the cover of the Society's first Journal, published in 1943.

Acknowledgements

The Editors would like to thank the anonymous reviewers who have contributed considerably to maintaining the quality of the scientific and other articles published here. Kevin Hutchinson and John Mc Loughlin have organised an interesting and very extensive book review section. Emma Golding has contributed to the editing, laying-out and formatting of the issue. Pat O'Sullivan has continued to play a huge role in the production of this and previous issues. His help and support are highly valued and appreciated.

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EDITORIAL

Mol an óige agus tiocfaidh sí.
Bual sa tóin í agus titfidh sí.

The next generation of foresters needs a more diverse range of skills than ever before. The entire sector (as well as the pension funds of current staff) is increasingly reliant on its ability to respond to many changes in circumstances and conditions in the forest estate, as well as society's interactions with it. Mirroring the skewed nature of the forest estate, a similarly skewed age profile of the professional staff in the sector means that in recent years there has been increased numbers of forestry job postings. With a selfish and often wistful eye on those pensions, it behoves all of us to make sure we are attracting the very best calibre of students and new professionals into forestry and related areas. Indeed, this may be a good time to consider the difficulties arising from the forestry sector's poor public image. Despite being a successful sector, economically and environmentally, there is still a widespread misunderstanding of what forestry is about. While this continues, it will be very difficult to attract the calibre of entrants required to serve the industry and profession.

Students and new professionals are needed not only to cope with buying/selling timber and planting new sites, but will also have to respond and adapt to changes caused by alterations in climate, markets, a wider diversity of tree species and increased threats from pests and diseases. Greater silvicultural and ecological knowledge will be needed to manage a wider portfolio of species and to adapt to such changes. Therefore, it is critical that new entrants to the sector play to strengths from the practical and field-related to the more academic and theoretical. We need good students certainly, but we also need to give them good opportunities to gain experience on-the-ground. In this profession more than any other we know the value of investing not only in tomorrow, but also far into a long rotation where we can expect much altered conditions. Let's hope that not too many succumb to the ridiculing retort to the above *seanfhocal* but instead act constructively to bring about change.

To prevent a decline in student calibre, career development teachers should be helped to direct students to a profession that already calls for a wide variety of skilled expertise spanning establishment and silviculture, from GIS and remote sensing technologists, to wood science specialists, to botanical and ecological experts and from research scientists to financial wizards and economists. How else shall we hope to fertilise our ranks to create a dynamic and innovative industry that will provide inspirational and reliable leadership?

To achieve this, a much better appreciation of forestry and its value by society is needed – this is in our hands! Perhaps there is need for direct input to primary and secondary school education (e.g. why does forestry not play an important role in the secondary schools' Agricultural Science curriculum?), to general television and other media programming, or to organising targeted local forest walks. It is clear from the number of books published on trees and forestry-related subjects (see the list of recent publications in the Book Reviews section) that there is a huge appetite for and interest in things natural. Our challenge is to harness and channel this interest towards a better understanding and appreciation of forestry.

This issue of *Irish Forestry* contains a wide variety of papers on practical aspects of forestry such as silvicultural advice on site considerations and nursing effects on cutaway peats (Black et al. papers). Coates et al. and de Miguel et al. describe the case for short rotation forestry and some of the issues affecting its potential in Ireland. Walsh et al. provide a useful discussion of "minor conifers" and how they may be used to replace larch in response to increasing threat from *Phytophthora* diseases. Fennessy adds to this discussion with advice on the use of Monterey pine. Afforestation targets (both across the EU and in Ireland) are considered by a series of authors from very different perspectives. From Ryan et al., who consider the effects of taxation measures, to Huss who reflects on the attitude to planting broadleaved species in the wake of the publication of *Broadleaf Forestry in Ireland* (a review of which appears herein also). This is topical as the afforestation grant-aid for broadleaved species has recently been increased. A captivating article by O'Brien on the historical timber trade in the south east of Ireland from 1200 onwards describes the ebb and flow of timber exports in the context of forest cover in the region. There is also a fascinating description of the sailing ships employed in this trade, which appear to have had quite an international circulation - for instance, the Canadian brigantine *Dei Gratia*, famous for salvaging the *Marie Celeste* in 1872, spent a period trading on the River Blackwater.

The role of forestry in climate change mitigation is another theme featured in this issue and Cabrera Berned and Nieuwenhuis discuss the implications of management intensification. Ryan et al. also further consider this theme and comment on the unequivocally positive role played by the forestry sector in such mitigation. In the context of potentially huge national fines being imposed for infringing UN climate change convention obligations, it would seem that not enough use is being made of the uniquely positive impact of forestry. It does not bode well that afforestation in 2017 is the lowest for almost 60 years. As Huss points out in his article about the potential for development of the forestry sector, the projected increase in harvestable material will bring about more jobs. However, the true potential of such produce, particularly from broadleaved species, is in real danger of not being fully realised. Thus, to protect the investment to date and to bring about a full return and turn over, it is imperative that we hold firm and continue to invest considerably in appropriate education specifically for current professionals, students and land owners/growers, but also for the general population.

The Society of Irish Foresters was established on Friday, 29th September 1942. The Society commemorated its 75th anniversary by launching a fine reprint of *The Sacred Trees of Ireland* by A.T. Lucas at a ceremony in the Phoenix Park Visitor Centre on the 29th September 2017. In addition, a digital version of *The Forests of Ireland* by H.M. Fitzpatrick has recently been made available on the Society's website. This book was published in 1966, in anticipation of the Society's silver jubilee, for the benefit of "the practising forester and of the general public." Neither the aspirations of the Society nor its closely-felt association with books about trees have changed much in the intervening period.

This year honorary membership was bestowed on two long-serving members, Ted Farrell and Bill Wright (see Figures 1 and 2).

In this anniversary of the foundation of the Society, it is particularly poignant to note the passing of Michael McNamara, the last surviving founding member of the Society, a man for whom the value of forests was "measured not just in narrow economic terms but in their total contribution to society".

Figure 1: *Niall Farrelly, President of the Society, presents the honorary membership medal to Ted Farrell, Emeritus Professor of Forestry at University College Dublin in recognition of his significant contribution to forestry education and research in Ireland*.

Figure 2: *Gerry Murphy, President of the Society of Irish Foresters, presents the honorary membership medal to Bill Wright in recognition of his service to forestry and his contribution to the Society of Irish Foresters in fulfilling its mission* "*to lead and represent the forestry profession which meets, in a sustainable manner, society's needs from Irish forests, through excellence in forestry practice*".

Estimation of forest biomass using L-band backscatter microwave satellite data

Kevin Black[a*], Maarten Nieuwenhuis[b], Fiona Cawkwell[c] and Preethi Balaji[c]

Abstract

Synthetic Aperture Radar (SAR) satellite data can be used to monitor spatial and temporal changes in forest biomass and timber volume. Previous research suggest the SAR L-band backscatter signals saturate at a relatively low stand biomass threshold, making the application limited to thicket stage crops. In this study, new biomass and L-band backscatter regression models were developed using procedures to reduce interference due to radar incidence angle and surface moisture and by applying cross-image calibration using both forest and non-forest plot data to increase the biomass saturation point for stand biomass and volume. Many of the widely published model formulations were found not to provide a suitable model fit because of non-normal distribution and evidence of heteroskedasticity of model residuals. The model re-developed in this study performed better than published models, based on lower Akaike Information Criteria values and no heteroskedasticity of model residuals. The backscatter saturation for the re-developed model occurred at biomass values of c. 100 Mg ha^{-1}, so accurate determination of biomass using this approach may be limited to immature forest stands. However, the L-band backscatter-biomass model may be suitable to detect changes in forest biomass or volume due to disturbance events.

Keywords: *Biomass regression models, Synthetic Aperture Radar, L-band backscatter.*

Introduction

Aboveground biomass represents an important component of forest carbon (C) and depletion of this C pool due to anthropogenic disturbances such as deforestation or forest degradation can lead to large greenhouse gas emissions. However, assessments of C loss due to deforestation and harvesting are subject to large uncertainties. Use of active remote sensing techniques, such as Synthetic Aperture Radar (SAR), have shown potential for monitoring spatial and temporal changes in forest biomass. Numerous studies have reported on the direct relationship between SAR backscatter signals (i.e. at the bands of longer wavelengths: P (30-100 cm) and L (15-30 cm)) and

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forest biomass (Ryan et al. 2012, Huang et al. 2015). In particular, full polarimetric SAR provides combinations of different transmitted and received polarisations, such as horizontally transmitted and vertically received backscatter (HV) signals, which have been shown to detect changes in forest biomass up to a saturation level of 100 to 200 Mg C ha^{-1}, depending on the SAR wavelength (C, L, P or S bands). L-band data from the PolSAR satellite have been used to monitor forest disturbance and assess biomass in tropical, boreal and sub-tropical regions (Ryan et al. 2012, Robinson et al. 2013).

A number of factors can affect the relationship between forest biomass and L-band backscatter signals, such as radar incidence angle, changes in surface dielectric properties due to moisture and differences in surface roughness. Therefore, numerous cross-image normalisation and adjustment procedures may be required to provide reliable estimates of forest biomass (Huang et al. 2015). Another confounding factor is that L-band signal saturation for forest biomass occurs at 50 to 100 Mg ha^{-1}. Typical conifer plantations in Ireland already contain at least 50 Mg ha^{-1} before first thinning events, so L-band signals may not be sensitive enough to detect intermediate harvest events or accurately assess timber volume biomass in mature stands.

Biomass-backscatter regression models have been developed using field measurements and corresponding L-band signal data (Dobson et al. 1991, Huang et al. 2015). Given the non-linear nature of the relationship between the L-band backscatter signal and biomass values, transformation of the data is required in order to simplify the curve-fitting procedure. However, few studies have assessed the effectiveness of such data transformations in terms of overall regression model performance. Moreover, little consideration has been given to the analysis of normality and heteroskedasticity of model residuals to test data transformations, model forms and performance. This may result in a biased estimation of biomass, particularly in the range where L-band signals for biomass are saturated.

In this study, we assessed the performance of biomass and L-band backscatter-regression models to accurately detect changes in biomass due to forest disturbance by a) applying procedures to reduce interference due to variations in radar incidence angle and surface moisture, b) cross image calibration using forest and non-forest plot data to increase the biomass saturation point and c) comparing different data transformations and model formulations.

Materials and methods

Study area and SAR data

The study area covers four different regions of Ireland (Figure 1), representing forest and site types. The soil type across sites varied from wet peatlands in the west to drier mineral soils in the Wicklow mountains in the east. Topography varied from flat lowlands in Kildare and Carlow to mountainous regions in Wicklow and Cork.

The Phased Array-type L-band Synthetic Aperture Radar (PALSAR) on-board the Advanced Land Observation Satellite (ALOS) operated from January 2006 to May 2011 (Rosenqvist et al. 2007). The PALSAR instrument operated at L-band (λ~24 cm) offering fully polarimetric features. The scenes were acquired in Fine Beam Dual-Polarisation (FBD) mode (horizontal transmit and horizontal receive (HH) and horizontal transmit and vertical receive (HV)) from ascending orbits which had a recurrence cycle of 46 days. The incidence angle of each image at scene centre was approximately 38°. To cover the entire study area, two frames of the same acquisition date were acquired. Data were acquired for the summer months of May-June (2007-2010) for this study (Figure 1). The data frames ordered for sites in Cork, Donegal, Wicklow and Mayo included some portions of neighbouring sites as can be seen in Figure 1.

SAR Pre-processing

Through the European Space Agency (ESA) Category -1 proposal (Id 17771), single look complex (SLC) products were acquired. PALSAR 1.1 level dual polarised SLC data were multi-looked at one time in range and four times in azimuth direction to create 15 × 15 m pixels. After co-registration of the images, the data were filtered using a DeGrandi multi-temporal speckle filter to reduce speckle. The images were calibrated radiometrically and geometrically and the digital number was converted to decibel (dB) using Eq. 1 from Shimada et al. (2014) and Woodhouse (2006).

$$\gamma^{\circ} = \frac{\sigma^{\circ}}{cos\theta} \qquad [1]$$

where, γ° is the backscattering coefficient normalised with the cosine of the incidence angle, expressed in dB, σ° (Backscattering coefficient or differential radar cross-section) = $10 \times \log_{10}$ (DN); DN is the pixel digital number value in HH or HV, and θ is the local incidence angle.

To ensure proper geometric correction of the SAR scenes, an OSi Digital Elevation Model (DEM) of 10 m spatial resolution and many ground control points (GCPs) was used. The scenes were geometrically corrected to the Irish Transverse Mercator (ITM) projection. Terrain-induced distortions such as layover and shadowing were masked off from the images. The local incidence angle (angle between the normal to the backscattering element and the incoming radiation) generated by the DEM was used to identify the layover and shadowed areas, where negative values represented active layover areas and values greater than 90° represented active shadow areas. Finally, the two frames covering each study site were mosaicked. The SAR processing steps were carried out using SARscape 5.0.001 software within an ENVI environment of version 4.8.

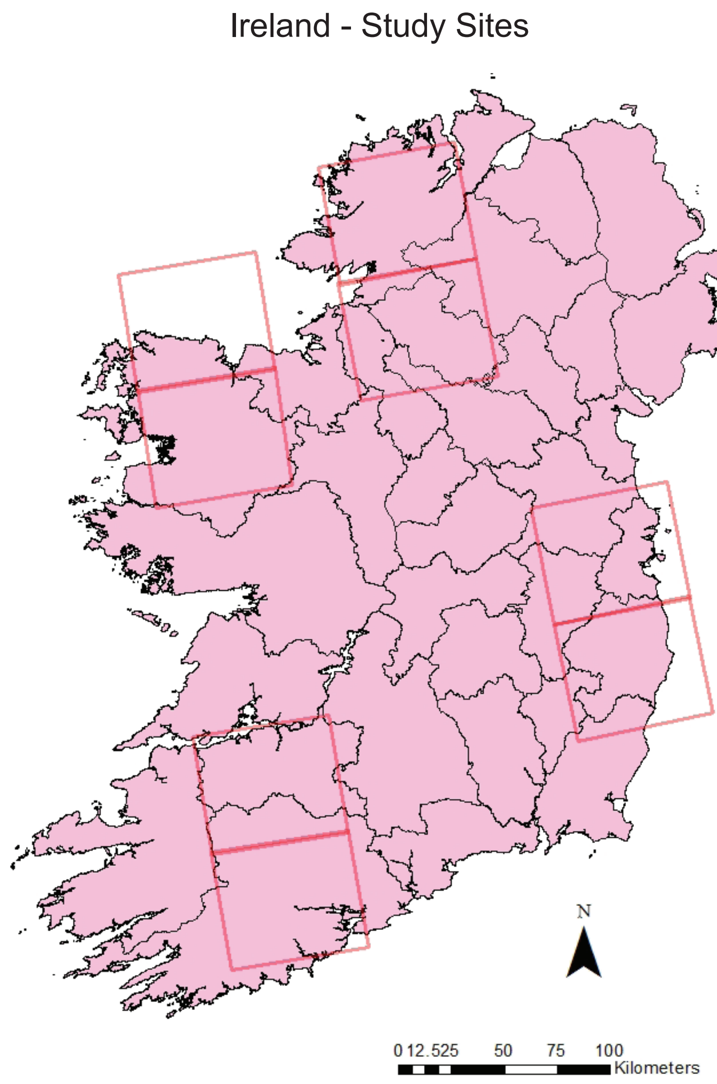

Figure 1: *Areas covered by the acquired data frames (red boxes).*

Correction for incidence angle

Even after the rigorous radiometric calibration, variations in the backscatter coefficients can be observed. This is due to the dependence of backscatter energy on the incidence angle. To equalise these variations, SARscape applies a cosine correction to the backscattering coefficient in the radiometric correction and normalisation step of the SAR processing. This is based on a modified cosine model by Ulaby and Dobson (1989).

Correction of backscatter signals for soil moisture and cross image normalisation

Huang et al. (2015) outlined the sensitivity of the backscatter signals to soil moisture, which masks the biomass-backscatter response, particularly in the biomass value ranges from non-forest to pre-maturity (i.e. before saturation point). The authors propose a two-step normalisation procedure. The first backscatter correction (σ'^{o}_{o}) makes use of the saturation point of a near-mature forest (S1) relative to the original target backscatter signals from the National Forest Inventory (NFI) (σ^{o}_{o}) in order to increase the biomass saturation point at higher levels of biomass. The second step normalises the signal (σ''^{o}_{o}) using the backscatter signals (S2) of both the near-mature forest (S1) and a nearby clearcut area, to reduce the impact of the soil moisture signal by subtracting it from the total signature. Detailed methodologies are outlined by Huang et al. (2105).

Reference clearfelled stands (S2) and mature stands (S1) were selected within a 3 km radius of the target plot (i.e. NFI plot) using Coillte Teoranta's (Irish Forestry Board) forest parcel inventory database. L-band backscatter HV signals for the reference stand were processed and corrected for angle of incidence using the same procedures described in the sections above. Reference stands were selected using the buffer proximity function in ArcGIS v10.2. All S1 stands were selected using a biomass threshold value of 350 Mg ha^{-1}, which is well above the backscatter signal saturation point. The status of S1 stands was visually verified using 2011 Bing imagery orthophotographs. It was assumed that a mature stand in 2011 would still have a biomass value well above the signal saturation level of c. 100 Mg ha^{-1} in 2007. The status of S2 stands was verified using Coillte's management and felling records for 2006 and 2007.

Field data

Biomass data for target SAR L-band backscatter values in the HV polarisation were derived from the 2007 NFI (Forest Service 2007a). The NFI is based on a random stratified permanent sample system, from which c. 2,000 500 m^2 permanent plots are measured for tree and stand metrics. Biomass and timber volume are provided by the NFI (Forest Service 2007b) using biomass algorithms and stem volume equations published by Duffy et al. (2013) and Black (2016). The biomass component represents all aboveground elements including stems, branches and leaves above a stump height of 1% of total tree height. Timber volume was assessed from a stump height of 1% of total tree height to a top end diameter of 7 cm. A total of 450 permanent sample plots were identified in the selected study area, of which 297 were selected for analysis (SAR data were not available for the remainder), which was required when calibration and corrections to the backscatter data were made. A statistical summary of the selected plots is shown in Table 1. The aboveground biomass (AGB) for the

Table 1: *A statistical summary of selected plots used for the biomass and volume regression models.*

Parameter	Mean	Min	Max	N
Stocking	1,124	0	3,578.0	297
Basal area (m^2 ha^{-1})	15	0	73.0	297
DBH (cm)	22	0	53.7	297
AGB (Mg ha^{-1})	222	0	788.0	297
Volume (m^3 ha^{-1})	157	3	650.0	207

297 plots varied from 0 to 788 Mg ha^{-1}. Timber volume was derived for 207 of the 297 plots with a range of 0 to 650 m^3 ha^{-1} (50 plots were temporarily unstocked, and 40 contained trees with a DBH less than 7 cm).

Regression models for biomass mapping

A range of curve fitting procedures were tested to select the most suitable regression model to predict biomass from the HV backscatter signals. Three curve functions were compared using linear regression analysis and model testing procedures in the R studio package (Venables and Ripley 2002). The first function is the published exponential model (Eq. 2), which describes the non-linear relationship between biomass and backscatter signals (Huang et al. 2015).

$$AGB = e^{a+b\sigma_o^o} \quad [2]$$

where, *AGB* is aboveground biomass (Mg ha^{-1}) and σ_o^o is the incidence angle corrected L-band HV backscatter signal (dB). The equation was rearranged to facilitate linear regression modelling (Eq. 3, Model 1).

$$\ln(AGB) = a + b\sigma_o^o \quad [3]$$

The second function (Eq. 4, Model 2) is an inverse exponential model. This is fundamentally different since here AGB is assumed to be proportional to the inverse of σ_o^o rather than untransformed σ_o^o.

$$\ln(AGB) = a + 1/b\sigma_o^o \quad [4]$$

The final model (Eq. 5, Model 3) assumed that the relationship is best described using a hyperbolic function. This best suits the assumption that biomass is fully saturated in mature forest, while exponential functions never reach an asymptote.

$$1/\mathrm{AGB} = a + b(1/\sigma_o^o) \quad [5]$$

To select the best model, a number of goodness of fit parameters were tested, such as root mean square error (RMSE), bias and coefficient of determination (R^2). Further regression analysis of predicted and observed values was performed together with a normality test on model residuals using the Shapiro-Wilk statistic in the R studio. The distribution frequency was considered not to be normal if the p-value of the Shapiro-Wilk estimate was less than 0.05. We also used Akaike Information Criteria (AIC) for model selection to avoid over parameterisation of the model (see Burnham and Anderson 2002), based on the assumption that the lowest AIC values were optimal.

Once the best biomass model was selected, the three separate normalisation and correction backscatter estimators were tested to assess if the signal correction and cross image normalisation procedures improved the prediction of biomass.

Finally, all backscatter variables (i.e. σ_o^o, ${\sigma'}_o^o$ and ${\sigma''}_o^o$) and additional predictors, such as moisture index (SMR), soil nutrient index (SNR), topographical index (TPI), elevation, aspect, slope and radar angle on incidence (RAI) were added to the model using multiple regression modelling in a forward stepwise manner using an R studio (Venables and Ripley 2002). The best model fit was selected based on AIC, with new variables included in the model only when AIC was lower than the initial or last model iteration. The values for SMR, SNR and TPI were derived from an ecological site classification model described for Irish forests by Ray et al. (2009) and Black et al. (2014). The SMR index is based on water holding capacity and SNR is the soil nutrient status of different soil types in the NFI plots. TPI was used as an indicator of topex (Black et al. 2014). These variables were selected because they may influence the backscatter signal and further explain variation in biomass at a given backscatter value.

Results

SAR correction and normalisation

The angle of incidence corrected SAR L-band backscatter values, in the HV polarisation (σ_o^o) ranged from -28.22 to -12.82 dB (Table 2). The first step correction (${\sigma'}_o^o$) did not have any significant effect on the data structure in terms of the frequency distribution and the range of observed values (Table 2). The cross-image normalisation (${\sigma''}_o^o$) did, as it increased the backscatter value range by -1 to 5 dB and skewed the frequency distribution to the right (i.e. higher 3rd quartile percentage and maximum dB values, compared to the non-normalised data, Table 2).

Biomass model selection

The first step was to select the best curve fitting procedure using the three models (Eqs. 2, 3 and 4). Goodness of fit estimators showed that model 1 (i.e. the exponential model, Eq. 2) provided the best fit, in terms of the lowest RMSE, bias, AIC and R^2 values and the highest F-value from AVOVA (Table 3).

All regressions equations and coefficients were significant at $P < 0.001$. However, the Shapiro-Wilk test on model residuals (i.e. observed minus predicted AGB values)

Table 2: *Summary statistics for HV backscatter signals following different correction and normalisation procedures.*

HV signal	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
σ^o_o	-28.22	-21.09	-18.22	-19.05	-16.82	-12.82
σ'^o_o	-28.66	-21.34	-18.63	-19.27	-16.94	-12.71
σ''^o_o	-29.20	-20.92	-18.10	-18.83	-15.48	-7.45

Table 3: *Biomass-backscatter curve fit statistics based on the HV backscatter values corrected for angle of incidence (σ^o_o). F-values for ANOVA and Shapiro-Wilk values for normality tests are significant at P <0.0001 (***).*

Fit parameter	Model 1	Model 2	Model 3
RMSE	121.3	125.2	127.4
Bias	2.14	-7.6	11.8
R^2	0.54	0.43	0.38
F-value	343 ***	217 ***	190 ***
AIC	187	195	275
Shapiro-Wilk	0.46 ***	0.53 ***	0.85 **

suggested that the data were not normally distributed (Table 3). All model residuals also displayed uneven distributions across the observed AGB range, suggesting a problem of heteroskedasticity. For example, plots of Model 1 residuals displayed a fan shaped pattern, characteristic of heteroskedasticity, where residual errors increased as AGB increased (see top right panel in Figure 2). It is also evident that model 1 significantly underestimated biomass at the AGB range above 400 Mg ha^{-1} (Figure 2 top right panel).

In order to further refine the performance of AGB regression model, the angle of incidence corrected backscatter predictive values (σ'^o_o) used in Model 1 were substituted with the step 1 corrected (σ'^o_o) and step 2 normalised (σ''^o_o) values and tested for goodness of fit. Although the 1st step correction (σ''^o_o) was supposed to increase the backscatter signal saturation point and improve on the AGB prediction, this model did not perform any better than model 1 (Table 3). In contrast, the higher AIC for Model 4 suggested the goodness of fit decreased slightly.

Cross-image normalisation of backscatter for soil moisture did appear to increase model performance (Model 5, Table 4 and Figure 2), when compared to the other models, in terms of a lower AIC and RSME values. Analysis of residuals suggested a non-normal distribution of residuals based on Shapiro-Wilk. Residual plots also show a slight skewing of the frequency distribution, but with no systematic bias in the prediction at high or low observed AGB values (bottom right panel in Figure 2). The residual error for Model 5 also appears to be more normally distributed about the observed AGB data

Table 4: *Biomass-backscatter model selection using the best curve fit (Model 1) and different corrected and normalised HV backscatter values. The RMSE and bias estimates are based on the observed and predicted AGB values, not the ln(AGB). F-values for ANOVA and Shapiro-Wilk values for normality tests are significant at P <0.0001 (***), P <0.01(**) and P <0.05(*).*

	Backscatter value		
Fit parameter	**Model 1** σ^o_o	**Model 4** σ'^o_o	**Model 5** σ''^o_o
RMSE	121.3	123.4	119.7
Bias	2.14	3.44	2.32
R^2	0.54	0.53	0.58
F-value	343 ***	299 ***	361 ***
AIC	187	199	167
Shapiro-Wilk	0.46 ***	0.59 ***	0.38 *

range, when compared to the scatter plot for Model 1, thus indicating that cross-image normalisation may reduce the occurrence of heteroskedasticity of model residuals.

The final step of the model development was to introduce additional terms into a multiple regression equation to ensure normal distribution of model residuals. Site aspect were also tested in the model because a digital elevation model (DEM) was used to correct backscatter values for angle of incidence. Inclusion of aspect and satellite angle of incidence in the predictive biomass model did not reduce the AIC value so

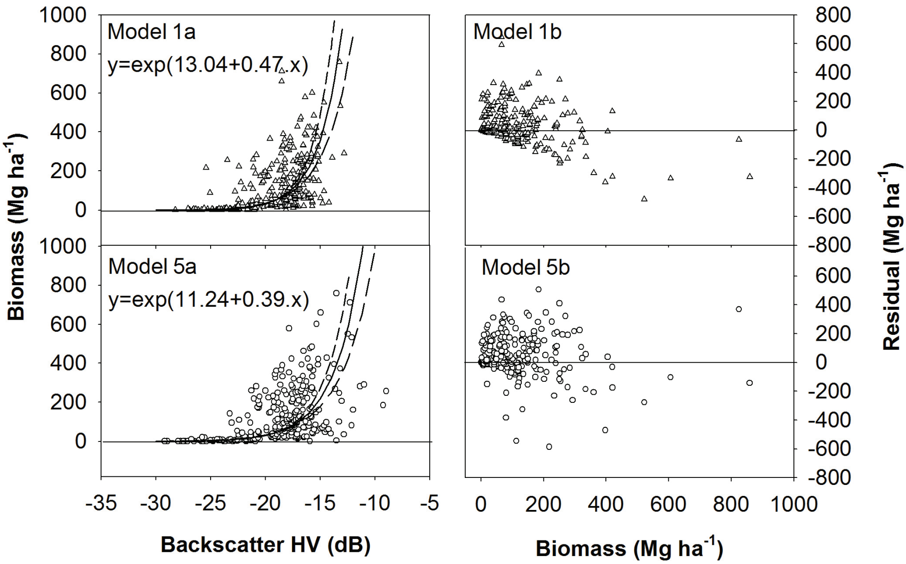

Figure 2: *Scatterplots showing the relationship between HV backscatter signals and observed AGB values from NFI plots (left panels, a) and residual versus observed AGB plots (right panels, b) for model 1 and model 5. The solid line plots in the left panels show the fitted regression curves for the models with 95 % confidence intervals (dashed line plots).*

these variables were excluded from the model. A plot of Model 5 residuals against aspect and angle of incidence did confirm that these factors were not contributing to the non-normality (i.e. bias) of model residuals (data not shown).

The final model selection was based on forward model selection using AIC as the selection criteria. The stepwise regression started with Model 1; predictors were then added to the multiple regression in steps provided their addition resulted in a reduction in the model AIC value (Table 5). The final Model (Eq. 6, Model 4) included all backscatter signal correction and normalisation values and the digital elevation (Alt, m) of the site, as assessed during the NFI plot surveys:

$$\ln(AGB) = a + b_1\sigma_o^o + b_2\sigma'^o_o + b_{31}\sigma''^o_o + b_4Alt \quad [6]$$

The same procedure was carried out to develop a predictive model for timber volume (vol, m^3 ha^{-1}), but the final model produced the best AIC fit with less terms (Eq. 7, Model 5).

$$\ln(vol) = a + b_2\sigma'^o_o + b_3\sigma''^o_o \quad [7]$$

The initial AGB Model 1 had a corresponding AIC value of 187 and the final model produced an AIC value of 158 (Table 5). Addition of the predictors SMR, slope, radar angle of incidence (RAI) and TPI did not improve on model performance (i.e. AIC values were >158).

The final model provided the best estimation of AGB in term of the lowest AIC value. More importantly, all linear regression model assumptions were robust given that model residuals were normally distributed based on the Shapiro Wilk value test (Table 5).

The initial timber volume model used the intercept (a) and σ_o^o for forward stepwise model selection, resulting in an initial AIC of 36, and a final AIC value of 24 (Model 7, Table 5). However, analysis of residuals for Model 7 suggests a non-normal distribution, indicating that estimation of timber volume is not valid across the observed timber volume range (i.e. the Shapiro-Wilk value was significant, Table 5).

Detection of clearfell events

It was not possible to model clearfell events using the NFI data because only three occurred across all of the selected NFI plots over the period 2007 to 2011.

Discussion

Huang et al. (2015) used the same model formulations initially used in this study (i.e. Eq. 2) and predicted similar values for the solved coefficients a (12.4) and b (0.6) using corrected and normalised values from PULSAR HV, when compared to the findings presented in this study (i.e. model 5, Figure 2). They reported a better

Table 5: *Fitted coefficients with standard error in parenthesis and performance of the final models (Model 6) for biomass (AGB, Mg ha^{-1}) and (Model 5) for timber volume (vol, m^3 ha^{-1}) using forward stepwise multiple regression. The RMSE and bias estimates are based on the observed and predicted AGB and volume values, not ln(AGB) or ln(vol). F-values for ANOVA and Shapiro-Wilk values for normality tests are significant at P <0.0001 (***) and P <0.01(**).*

Coefficient/Parameter	ln(AGB), Model 6	ln(vol), Model 7
a	13.515 (0.571)	8.041 (0.576)
$b_1\ (\sigma^o_o)$	0.043 (0.013)	n.s.
$b_2\ (\sigma'^o_o)$	0.221 (0.077)	0.066 (0.035)
$b_3(\sigma''^o_o)$	0.218 (	0.132 (0.031)
$b_4(Alt)$	-1.125E-03(7.65E-04)	n.s.
RMSE	97.4	132.0
Bias	0.61	49.10
R^2	0.61	0.17
F-value	93***	24**
AIC (initial)	187	36
AIC (final)	158	24
Shapiro-Wilk	2.70	0.94**

model fit, compared to our model 5 (Table 4), in terms of a higher R^2 (0.65) and a lower RMSE (45 Mg ha^{-1}). However, Huang et al. (2015) and others (Ryan et al. 2012) provided no information regarding the goodness of fit in terms of model residual analysis. In our study, we found that the widely used model formulation does not provide a suitable fit because of the non-normal distribution of model residuals, and evidence of heteroskedasticity (see Figure 2a, Table 4). The main reasons for heteroskedasticity and a non-normal distribution of model residuals include: a) use of inappropriate model formulations (i.e. selection of unsuitable equation types to suit the data pattern), b) exclusion of predictive variables that may better characterise variations in biomass or c) inadequate data normalisation procedures of model predictors or observed values. Transformation prior to regression analysis and subsequent normality testing of predicted and biomass data and testing of different model formulations confirmed that omission of parameters that are in fact contributing to the variation in the data creates the conditions of bias in the model. Upon visual interpretation of the scatterplot for biomass versus backscatter singles, one may consider that a hyperbolic curve may be a more representative model formulation. However, based on the presented curve fitting comparisons, it is apparent that the widely used exponential curve appears to be most appropriate model to apply (Table 3). The correction for backscatter saturation did not appear to improve model performance, when compared to un-corrected values (Table 4). However, by using the cross-image normalisation procedure proposed by Huang et al. (2015) and by including additional variables in a multiple regression model, we demonstrated that issues of heteroskedasticity and non-normal distribution of residuals can be resolved (Table 4).

It was not clear if the backscatter interference due to moisture variations were completely resolved using the cross-image normalisation procedure proposed by Huang et al. (2015). This can perhaps be further refined using empirical approaches based on detailed climatic data for all radar scenes and for multiple observations on sampled data from non-forest and mature forest reference sites.

The analysis suggests that HV backscatter corrections for radar angle of incidence may have been adequate because inclusion of the angle of incidence in the multiple regression did not improve model performance. Although the HV signal was corrected for angle of incidence using DEMs, since altitude (*Alt*) was still found to be a significant predictor of biomass from backscatter signals, but it may be suggested that the resolution of the DEM was not sufficient to adequately correct for angle of incidence. Interestingly, the negative slope of the coefficient for *Alt* (see b_4 for model 6, Table 5) indicated that stand/site biomass decreased as altitude increased. Such a finding is consistent with currently used forest ecological site classification models (Ray et al. 2009, Black et al. 2016).

Use of L-band backscatter signals to predict forest biomass do not appear to be sufficient to provide precise estimates at the higher ranges (>100 Mg ha^{-1}) - as indicated by the high RMSE values, the larger confidence intervals where the backscatter signal saturated and the heteroskedasticity problem for the timber volume model. The model estimates for biomass, developed in this study is consistent with previous suggestion that backscatter saturation occurs at c. 100 Mg ha^{-1} (Figure 2, Ryan et al. 2012), so accurate determination of biomass using this approach may be limited to immature forest stands up to the first thinning stage for conifer crops (stand ages 16-25 years old). It is suggested that use of a longer wavelength P-band may be a more suitable approach to prediction of biomass and volume at higher levels (Dobson et al. 1991). However, L-band backscatter-biomass models may be suitable to detect changes in forest biomass or volume due to clear-felling or catastrophic disturbance events. Unfortunately, this could not be validated in the current study area due to the limited number of NFI plots that were clear-felled between 2007 and 2011.

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References

Black, K., Creamer, R.E., Xenakis, G. and Cook, S. 2014. Improving the YASSO forest soil carbon model using spatial data and geostatisitical approaches**.** *Geoderma* 232–234: 487–499.

Black, K. 2016. Description, calibration and validation of the CARBWARE single tree-based stand simulator. *Forestry* 86(1): 55-68.

Burnham, K.P. and Anderson, D.R. 2002 *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. 2nd edition Springer-Verlag, New York.

Dobson, M.C., Ulaby, F.T., LeToan, T., Beaudoin, A., Kasischke, E.S. and Christensen, N. 1992. Dependence of radar backscatter on coniferous forest biomass. *IEEE Transactions on Geoscience and Remote Sensing 30*: 412–415.

Duffy, P., Hyde, B., Hanley, E., O'Brien, P., Ponzi, J. and Black, K. 2013. *National Inventory Report; Greenhouse Gas Emissions 1990 – 2011. Reported to the United Nation Framework Convention on Climate Change*. Environmental Protection Agency, Dublin.

Forest Service. 2007a. *National Forest Inventory Republic of Ireland- Methodology.* Forest Service, Department of Agriculture Fisheries and Food. Available at http://www.agriculture.gov.ie/media/migration/forestry/nationalforestinventory/nationalforestinventorypublications/4350NFIMethodology.pdf [Accessed September 2015].

Forest Service. 2007b. *National Forest Inventory Republic of Ireland- Methodology.* Forest Service, Department of Agriculture Fisheries and Food. Available at http://www.agriculture.gov.ie/media/migration/forestry/nationalforestinventory/nationalforestinventorypublications/4350NFIMethodology.pdf [Accessed October 2017].

Huang, W., Sun, G., Ni, W., Zhang, Z. and Dubayah, R. 2015. Sensitivity of multi-source SAR backscatter to changes in forest aboveground biomass. *Remote Sensing* 7: 9587–9609.

Ray, D., Xenakis, G., Tene, A. and Black, K. 2009 Developing a site classification system to assess the impact of climate change on species selection in Ireland. *Irish Forestry* 66: 101–122.

Robinson, C., Saatchi, S., Neumann, M. and Gillespie, T. 2013. Impacts of spatial variability on aboveground biomass estimation from L-band radar in a temperate forest. *Remote Sensing* 5: 1001–1023.

Rosenqvist, A., Shimada, M., Ito, N. and Watanabe, M. 2007. ALOS PALSAR: A pathfinder mission for global-scale monitoring of the environment. IEEE *Transcripts in Geosciences and Remote Sensing* 45: 3307–3316.

Ryan, C.M., Hill, T., Woollen, E., Ghee, C., Mitchard, E., Cassells, G., Grace, J., Woodhouse, I.H. and Williams, M. 2012. Quantifying small-scale deforestation and forest degradation in African woodlands using radar imagery. *Global Change Biology* 18: 243–257.

Shimada, M., Itoh, T., Motooka, T., Watanabe, M., Shiraishi, T., Thapa, R. and Lucas, R. 2014. New global forest/non-forest maps from ALOS PALSAR data (2007–2010). *Remote Sensing of the Environment* 155: 13–31.

Ulaby, F.T. and Dobson, M.C. 1989. *Handbook of Radar Scattering Statistics for Terrain*. Artech House.

Venables W.N., Ripley, B. D. 2002. *Modern Applied Statistics with R.* Fourth edition. Springer.

Woodhouse, I.H. 2006. *Introduction to Microwave Remote Sensing*. Taylor and Francis, Boca Raton.

Effects of peat depth and aeration on species performance in afforested industrial cutaway peatlands

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Abstract

Many of the current recommendations for afforestation of industrial cutaway peatlands in Ireland are based on findings from trials established under the BOGFOR programme. These recommendations, however, were based mainly on observations from pre-thicket stage crops and questions, such as the long-term nutritional status of established crops and productivity of various species, remained unanswered. In this study, the performance of selected species was reviewed across a range of previously established experimental trials and demonstration areas. Preliminary investigation highlighted nutritional check and dieback on Norway (*Picea abies*) and Sitka (*Picea sitchensis*) spruce crops at 6 to 20 years after establishment. To identify the causes of this, detailed peat depth/type surveys, foliar analysis and conventional mensuration assessments were carried out across selected areas in both the demonstration and experimental sites. Results suggest that peat depth and aeration is a major factor influencing the productivity of afforested species and that afforestation potential of Norway and Sitka spruce may be limited to shallow peat depths (0.5 to 1.2 m), with other species such as hybrid larch, lodgepole pine, Scots pine and birch being more suitable for planting on deeper peat sites (>1 m deep). These findings contrast with previous recommendations for afforestation of cutaway peatlands in Ireland, but agree with current afforestation practice in Finland. We also suggest that the current nutritional management of established forests may need revision and a third fertilisation may be required to ensure sustained productivity of crops on industrial cutaway peatlands.

Keywords: *Peat depth, species suitability, cutaway peatlands.*

Introduction

The afforestation of industrial cutaway peatlands in this country could make a significant contribution to attaining the targets set out in the government's forest strategy. It is estimated that an area of between 16,000 and 20,000 ha of the Bord na Móna cutaway peatland resource has afforestation potential (for review see Renou-Wilson et al. 2008). Bord na Móna cutaways are extremely heterogeneous belowground, even though the landscape looks deceptively uniform in appearance

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from above. The peat varies in type, depth (because of the undulating topography of the underlying bog floor and local harvesting practices), pH, nutrient status, moisture regime (drainage) and in the geomorphology of the underlying (pre-bog) relict mineral soils. All of these factors influence the choice of future land-use programmes.

Much forest research has been carried out since the first cutaways became available for post-peat harvesting uses in the 1950s (reviewed in Renou-Wilson 2008). Since then, the emphasis has continually changed, as peat harvesting systems moved from being based partially on sod peat to exclusively milled peat, resulting in the development of new approaches to post-peat harvest utilisation, research and policies. Over the years, the main areas of investigation have included: grassland, agricultural crop production, horticulture, commercial forestry, biomass production, dry-land recolonization, wetland creation/restoration and recreational use. The options for post-peat harvesting use are determined to a large extent by the residual peat type and depth, hydrological constraints, geographic location and economic considerations. Although the initial trials on the afforestation of cutaway bog, established in the mid-1950s at Clonsast bog in Co. Offaly, gave encouraging results, significantly these were carried out on sod-peat cutaway which is a distinctly different medium to the milled peat situation that pertains nowadays. Other studies on *Phragmites* peats have suggested that their long term nutritional status may be the most limiting factor affecting successful afforestation, particularly in deeper peats (OCarroll 1966). The BOGFOR research programme made significant advances in developing guidelines for successful afforestation of cutaway peatlands (Renou-Wilson et al. 2008). The programme provided recommendations for selection of suitable peat and site types (mostly limited to *Phragmites* and woody fens), species, cultivation techniques and crop nutrition management for establishment of successful cutaway peatland forests. Many of the observations from trials established under the BOGFOR programme were limited, however, to pre-thicket stage crops (most assessments were made in crops less than six years old). In addition, many questions remained un-answered, such as the long-term nutritional status of established crops, productivity of different species and management of novel silvicultural systems.

The current practice of afforestation of cutaway peatlands in Ireland is based on criteria which differ to those proposed for conditions in Scandinavia. Afforestation of cutaways in Finland is generally restricted to peat depths less than 0.15 to 1 m, with Scots pine (*Pinus sylvestris* L.) being the major species of choice (Paavilainen and Päivänen 1995, Pietiläinen et al. 2005). Nutrient uptake on a very shallow (15 cm) peat layer has been suggested to increase due to root penetration through the peat layer into the nutrient richer mineral subsoil (Paavilainen and Päivänen 1995). Guidelines on peat depth for afforestation in Finland contrast the recommended practice at the time when many of the BOGFOR experiments were established, e.g. Jones and

Farrell (2000) suggested that the depth of the peat layer suitable for the afforestation of coniferous tree species should be at least 60 cm, so that the calcareous underlying tills or marls which are frequently present would not have negative impacts on the survival and growth of the trees.

Norway spruce (*Picea abies* (L.) H. Karst.) is now the preferred species for planting on cutaway peatland sites in Ireland because of its lower sensitivity to frost, compared to Sitka spruce (*Picea sitchensis* (Bong.) Carr., SS) (Renou-Wilson et al. 2008). In terms of natural regeneration, downy birch (*Betula pubescens* Ehrh.) is a pioneer species on cutaway peatlands while lodgepole pine (*Pinus contorta* Dougl.) or Scots pine will often regenerate if a suitable seed source is available locally. In Sweden, nutritionally richer peats can be colonised by Norway spruce (Svensson et al. 1998). Willow (*Salix* spp.) and birch (*Betula* spp.) have also been used as short rotation coppice crops in Finland (Hytönen and Kaunisto 1999), but establishment and maintenance costs for willow are suggested to be prohibitive for commercial plantations in that country (Kaunisto and Aro 1996).

The low nutrient status of partially cutover peatland is a serious constraint for successful afforestation. This was confirmed in the BOGFOR report (Renou-Wilson et al. 2008) and by earlier studies (OCarroll 1966), the results from which showed that the absence of phosphorus (P) was the key element affecting tree growth. The availability of potassium (K), and to a lesser extent nitrogen (N), was also identified as a potential limiting factor, depending on the nature of the peat remaining after harvesting. Cutaway peatland sites are inherently low in P compared with mineral soils and, although total N levels can be reasonably high, most of this is held in an organic form unavailable for tree growth. Potassium levels also tend to be generally low, the highest levels being associated with woody fen peats compared with *Phragmites* peats which have inherently lower levels of K (OCarroll 1966, Renou-Wilson et al. 2008). The depth of peat remaining following the cessation of harvesting can therefore affect the nutritional status of the peat soil.

In this study, a selected range of experiments and demonstration areas established under the BOGFOR programme were reviewed. The demonstration areas were established as large (10 ha) blocks of Norway spruce using, what were considered at the time (in 2000), the best available techniques. During the recent (2016) preliminary assessments of demonstration crops in Blackwater, Clonsast and Tumduff, it was noted that crop performance of Norway spruce (NS) was highly variable and sections of sites were not performing well, despite previously reported good performance of these crops after four years (Renou-Wilson et al. 2008). This raised concerns because these demonstration areas had been established using best practice at the time (but before results from the BOGFOR programme had become available). Similar issues have also recently been highlighted by data from sections of more recently planted cutaway sites (planted 2010/11) in Kildare, where Norway spruce is now showing early signs of severe nutrient deficiency and dieback.

There are numerous hypotheses suggested for the dieback and/or reduction in productivity: K deficiency (OCarroll 1966, Pietiläinen et al. 2005), water deficits, peat deterioration and lack of aeration in the root zone (Aro 2000). Soil and crop assessments were subsequently carried out to determine the cause of this dieback. To this end, detailed peat depth/type characterization, foliar analysis and conventional mensuration assessments were carried out across selected areas in both the demonstration and experimental sites.

Materials and methods

Selected experiments and demonstration areas

Selection of experiments or demonstration areas was confined to sites dominated by *Phragmites* or woody fen peats, based on recommended preference of these peat types for afforestation (from work by Renou-Wilson et al. 2008). Selection of species for assessment was limited to the major productive conifers planted on these site types for commercial forestry and birch, due to the prevalence of this species on cutaway peatlands (Table 1).

Plot surveys

Detailed survey plots were conducted to assess soil characteristics such as nutrition status, peat type, depth above the sub-soil layer, peat aeration and qualitative information relating to the performance of selected species, such as height and productivity. These data were collected using the Field Map system (IFER, Czech Republic) over the period October 2016 to February 2017. The location of survey plots was selected based on a random stratified sample of canopy height, based on a canopy height digital terrain model (DTM). Digital surface models (DSM, determine canopy height with a resolution of ±20 cm) and photo-imagery for red, green, blue and near infrared bands (Figure 1) were purchased from Blue Sky (imagery captured in May 2016). The height of the peat bays was determined using a digital terrain model (DTM) provided by Bord na Móna. Canopy height was determined using the difference between the DSM and DTM raster values (in m, Figure 1). The areas were then classified into 6 canopy height classes using equal interval segmentation methods using ArcGIS v10.1 (ESRI). Ground survey plots (2 m radius) were selected to represent good, moderate and poor sections of the crops to provide a cross section for further field evaluation (see yellow star symbols in Figure 1). A total of 140 plots were identified across the different sites.

The IFER field mapping system was used to navigate to the centre of each plot. Individual tree height was determined on 4 to 5 trees immediately adjacent to the centre of the plot using a Haglof Vertex IV ultrasonic device (Haglof, Sweden).

Table 1: *Details of the selected species and experimental/demonstration areas. A description of how estimated yield class (Est. YC) data were derived is given in the Materials and methods section. n.d. means not determined.*

Exp./Site	Species	Age	Description	Est. YC (m^3 ha^{-1} yr^{-1})
CLE 1/99	Norway spruce (NS)	17	Demonstration area	10
CLE 2/00	Hybrid larch (HL)	16	Cultivation and species	12
	Norway spruce (NS)	16	(replicated)	10
	Scots pine (SP)	16		10
	Sitka spruce (SS)	16		10
Derrybrennan	Norway spruce (NS)	5	Demonstration area	n.d.
Killinagh	Lodgepole pine (LP)	6	Demonstration area	n.d.
	Norway spruce (NS)	6		n.d.
KTY 1/99	Norway spruce (NS)	17	Demonstration area	10
KTY 14/00	Birch (BI)[a]	16	Mixed Species trial	8
	Sitka spruce (SS)	16		14
KTY 16/00	Hybrid larch (HL)	16	Cultivation and species	8
	Norway spruce (NS)	16	(replicated)	12
	Scots pine (SP)	16		12
	Sitka spruce (SS)	16		20
KTY 17/00	Lodgepole pine (LP)	16	Species demo area	8
TLM 35/96	Hybrid larch (HL)	20	Species trials	12
	Lodgepole pine (LP)	20	(duplicated)	8
	Lodgepole pine (LPS)	20		12
	Improved birch[a]	20		10
	Un-improved birch[a]	20		6
	Norway spruce (NS)	20		18
	Scots pine (SP)	20		12
	Sitka spruce (SS)	20		18

[a]All birch (BI) species are either *Betula pubescens* (Ehrh.) or *B. pendula* (Roth).

Peat cores were sampled in the centre of each plot using a 20 mm-diameter Gouge auger. Peat depth was measured to 2 m and a description was taken of the peat layer types and the extent of anoxic conditions in the deeper peat layers. The anoxic layer was defined as the region of the profile which exhibited any one of the following characteristics; a hydrogen sulphide smell, a change in colour of peat (usually to light brown or orange) due to no decomposition of organic material or a build-up of iron under anoxic conditions or a permanently water-saturated layer in the peat profile.

Foliar analysis

Foliar samples were collected where required in the winter of 2016/17 from some species trials and demonstration sites. Bulked foliar samples (from 4-5 trees) were collected from needles produced in 2016 from lateral branches in the top section of the canopy of

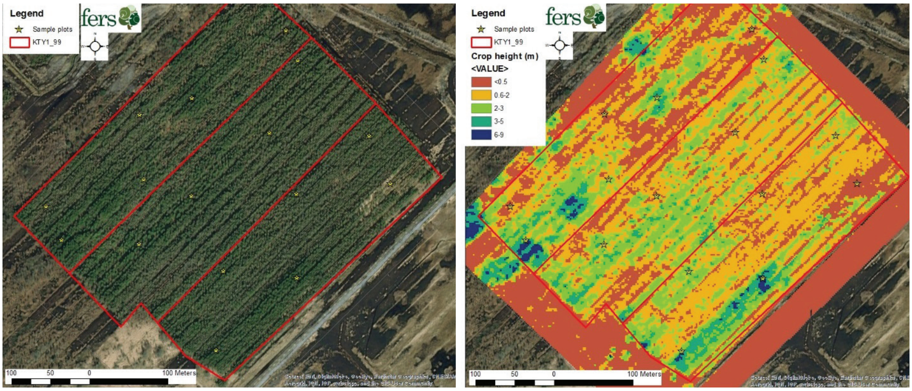

Figure 1: *A colour (RGB) image (left panel) and the canopy model derived from the DTM (right panel) of KTY 1/99 (NS demonstration area), showing different height classes (from brown (<0.5 m) to blue (6-9 m)) and location of selected plots (black circles).*

trees directly adjacent to the centre of the sample plot, where the peat sample was also taken. The foliar samples collected were dispatched immediately after collection to the Forestry Commission Research Laboratory in Alice Holt, Farnham, Surrey, England. The content of the following elements was determined in each: N, P and K. Foliar samples were dried at 70 °C prior to weighing to remove any residual moisture content. The combustion method for N determination was made using a Carlo Erba CN analyser (Flash1112 series) using 10 mg dried and ground needle samples. For P and K, c. 100 mg of dried sample was weighed into a 15 ml borosilicate (or quartz) tube. One ml of concentrated sulphuric acid was added to each sample with 0.8 ml of hydrogen peroxide (30%). The tubes were then incubated on a heating block at 335 °C for 30 min or until the digests were clear. The samples are made up to 15 ml with distilled water and then analyzed on a dual view ICP-OES analyser (Thermo ICap 6500).

Statistical analysis

<u>Assessment of productivity</u>

The mean height for each plot and each experimental treatment/species was derived from survey data. Top height for each experimental treatment or plot was determined using mean height regression equations (Matthews and Mackie 2006).

The mean height (H, m) for each plot was normalised (H at 16 yrs) so that a global analysis across sites varying in age (yrs) could be performed:

$$Normalised\ H_{16yrs} = \frac{H}{Age_{yrs}} \times 16 \qquad [1]$$

The growth response in different plots was then expressed as an <u>observed</u>

normalised ratio of height potential (H_{pot}), which described the relative decline in growth of each plot (mean plot height at 16 yrs) relative to the maximum plot mean normalised height (the maximum normalised plot height across the species strata) for each species (*j*) from all experiments at 16 yrs:

$$H_{pot(j)} = \frac{Plot\ Normanilsed\ H_{16yrs}}{Max\ Normalised\ H_{16yrs(j)}} \quad [2]$$

This ratio is indicative of the decline in growth associated with the site conditions, with 1 indicating no inhibition of growth and 0 indicating no growth. These variables were subsequently used for further statistical analysis.

<u>Pearson regression analysis</u>

Regression analysis was performed at the plot level to assess relationships between site variables (e.g. peat depth or foliar nutrient concentration) and tree performance. Raw data were transformed using a natural log transformation to ensure data were normally distributed (based on Shapiro-Wilk statistics) using the R studio software package (https://www.rstudio.com/), if required, prior to subsequent analysis. Regression analysis of single variable sets was performed using the Pearson's correlation coefficient (R). R values were determined to be significant based on the probability value (p) for the returned R coefficient and the degrees of freedom (number of samples (N) -1) using the R studio package.

<u>Peat depth/aeration regression model</u>

A multiple regression model was used to develop a predictive indicator of how different species performed on different peat substrates varying in depth and aeration. The analysis was confined to hybrid larch (*Larix* × *marschlinsii* Henry, HL), Norway spruce (NS), Sitka spruce (SS), downy birch (BI), lodgepole pine and Scots pine (Pines). The pine species were assigned to one cohort group because of limited representation of individual species across different peat depths. The model data set was derived from 140 plot assessments of 9 different experimental or demonstration areas (see Table 1).

In order to determine if a relationship existed between peat characteristics and tree height (H), normalised H was modelled for each species group (*j,* i.e. SS, HL, NS, BI or Pines) using the function:

$$Normalised\ H_{16yrs(j)} = H_{coeff(j)} \times Peat_{factor(j)} \quad [3]$$

where, H_{ceoff} is the height coefficient derived from the slope of the linear relationship between normalised H (see Eq. 1) and the ratio of tree H potential (H_{pot}, see Eq. 2) for each species (*j*).

$Peat_{factor}$ of each species (*j*) is a response variable to total peat depth (P_{depth}, *m*) and relative peat aeration ($P_{aeration}$), which was modelled using the non-linear multiple regression function:

$$Peat_{factor(j)} = res_j + a0_j \times P_{depth}{}^{-kd(j)} \times P_{aeration}{}^{ka(j)} \quad [4]$$

where, *res* is the residual correction for the modelled dataset, *a0* is the scalar correction coefficient, *kd* and *ka* are exponential coefficient describing the decline in growth (negative) as peat depth increased (*-kd*) or increase in growth as relative aeration increased (*ka*). ($P_{aeration}$) was the depth (m) of the aerated layer relative to the total peat depth (P_{depth}):

$$P_{aeration} = \frac{depth\ of\ anoxic\ layer}{P_{depth}} \quad [5]$$

But if depth of the anoxic layer was deeper than the maximum sample depth core (3 m), then $P_{aeration}$ =1.

The final model formulation was derived in an iterative manner by adding the variables, such as P_{depth} and $P_{aeration}$, to the model based on forward selection of variables in a stepwise multiple regression using the R-studio package. Variables and model coefficients were only included in the final model if the root mean square error (RMSE) decreased significantly and there was no significant bias in model residuals, based on the Shapiro-Wilk statistic in R studio.

Results

Description of peats

All plots were dominated by *Phragmites* or a mixture of *Phragmites* and woody fen peat types, except for two plots (one in Killinagh and one in Exp. 14/00), which had a shallow *Sphagnum* layer over deep *Phragmites* peat.

Peat depth varied within and across experimental plots. For example, in experiments KTY16/00 and TLM 35/96 (see Table 1), peat depth varied from less than 15 cm to over 2 m. Peat depth generally increased as the height of a bay increased but, in some cases, peat depth could vary by 1 m within a 5 to 10 m section of a single bay. The underlying calcareous material also varied across sites, with fine, un-weathered calcareous sediment deposits being the most prevalent underlying material. In some sites, such as TLM 35/96, weathered limestone calcareous material was present. These areas were generally well-drained and contained better crops.

Norway and Sitka spruce, in particular, did not perform well on deep peats with little or no other vegetation on site, or where *Calluna* was present on *Sphagnum*-dominated peat sites. The growth of the two spruce species appeared to slow down in the last 4 to 6 years, based on inspection of leader lengths. Birch and the two pine species seemed to perform better across the range of peat types and there was evidence of natural colonisation of these species across many of these sites. Hybrid larch was very productive, even on deep peats, but this species did not perform well in wet or poorly drained areas.

Relationship between performance and peat depth/aeration

The performance of all tree species investigated, in terms of normalised height, generally declined as peat depth increased (Figure 2). In addition, normalised tree height increased as peat aeration ratio increased, except when the peat layer was fully aerated (at a relative aeration ratio of 1), where variations in growth were to a larger extent associated with peat depth (Figure 2). There was no apparent relationship between tree height of birch and the relative aeration ratio of the peat in the plots investigated (Figure 2).

As seen from the scatter plots (Figure 2), the relationship between tree height and peat depth or aeration was best described by a second order non-linear function (Table 2). The best model fit describing these relationships suggests that c. 70% of the variation in normalised mean plot tree height across all species could be associated with variations in peat depth and aeration (see r^2, Table 2 and Figure 3).

When peat depth was used as the only predictor of tree height, the model described over 50% of the variation in observed tree height across all species. However, when peat aeration was included in the multiple variable regression equation, this described an additional 20% of the observed variation in tree height (Eq. 4). It is also evident from the lower values of the fitted parameter for P_{depth} (*kd*, Table 2) that Norway spruce and Sitka spruce displayed a greater decline in tree height as peat depth increased when compared to hybrid larch and the pines. Hybrid larch, however, appeared to be more sensitive to anoxic peat conditions, compared to the other species (see higher *ka* value for larch in Table 5). These trends are more clearly demonstrated in Figure 4.

Using the yield class thresholds defined by Ray et al. (2009), and based on the modelled scenarios presented in Figure 4 (left panel), it is evident that both Norway and Sitka spruce may only be suitable for planting on *Phragmites* or woody fen type peats when the peat depth is less than 1.2 m and sites are well drained (relative aeration = 1). Planting of these species on deeper peats would likely result in low productivity crops (yield class of less than 12 m^3 ha^{-1} yr^{-1}) under currently recommended management guidelines for establishment of cutaway peatlands. However, if drainage is not suitable and the aeration ratio is less than 0.5 (e.g. an anoxic layer of 0.6 m for a total peat depth of 1.2 m), then the model predicts that Sitka and Norway spruce would only be suitable for planting in peats to a depth of 0.3 m and 0.5 m, respectively (Figure 4, right panel).

The model predicts that hybrid larch can tolerate deeper peats (up to 2 m) so long

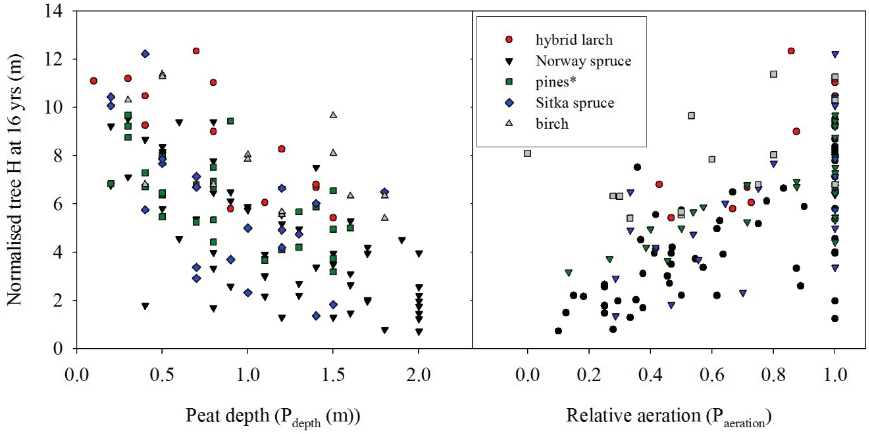

Figure 2: *Variation in mean plot normalised tree height at 16 years (H_{16yrs}) in relation to total peat depth (left panel) and relative peat aeration (right panel). See Equation 5 for description of* $P_{aeration}$ *ratio (n=140). * Pines are represented by both lodgepole and Scots pine species.*

Table 2: *Fitted model parameters (see Equations 3 and 4 for parameter and model description) and model goodness of fit variables for species specific functions.*

		Species			
		Hybrid larch	**Norway spruce**	**Pine**[d]	**Sitka spruce**
Model fit	r^{2a}	0.75	0.71	0.68	0.62
	RMSE[b]	0.654	0.874	1.324	1.161
	Bias	0.613	0.412	0.364	0.400
Solved parameters	H_{coeff}[c]	13.66 (0.11)	10.7 (0.05)	11.7 (0.07)	13.4 (0.021)
	res	0.374	-0.129	0.154	0.252
	a0	0.423 (0.051)	0.723 (0.081)	0.534 (0.065)	0.223 (0.054)
	kd	-0.121 (0.022)	-0.252 (0.038)	-0.157 (0.062)	-0.632 (0.084)
	ka	1.874 (0.321)	0.408 (0.016)	0.542 (0.094)	1.302 (0.321)

Note: The model for birch was not significant.
[a] r^2 is the coefficient of determination
[b] RMSE= root mean square error
[c] Model coefficients are presented with standard error values in parenthesis.
[d] Pine included lodgepole and Scots pine.

as a site is well-drained. However, it should be noted that the maximum sampled peat depth for HL was only 1.5 m, so extrapolating predicted growth beyond that depth is not recommended. Good drainage appears to be an important factor for hybrid larch. The model predicts that hybrid larch would not be suitable at any peat depth if the aeration ration is below 0.5 (Figure 4, right panel). The model suggests that both lodgepole and Scots pine appear to tolerate deep peats and anoxic conditions (Figure 4). The model predicts that pines would be suitable for 2 m-deep peats up to

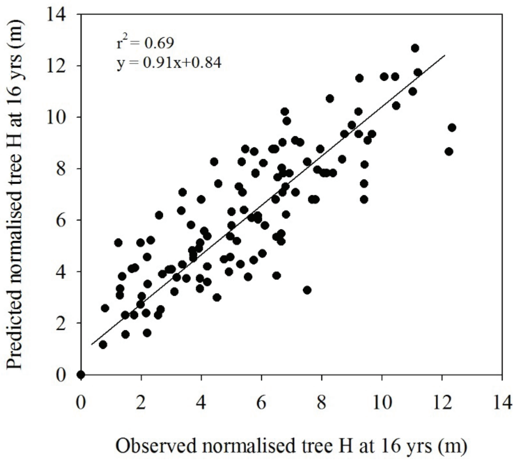

Figure 3: *Regression of observed versus predicted normalised tree H (n = 125) using the peat depth and aeration model (Equation 4). Note birch was excluded from regression because the model coefficients (Equation 4) were not significant.*

a $P_{aeration}$ ratio of 0.2 (data not shown). This trend was consistent with observations of extensive colonisation by pine species in deep peat areas of less well drained parts of *Phragmites* and woody fen sites, which generally did not support Norway or Sitka spruce. Although the model does not describe any variation in the height growth of birch, the data shown in Figure 2 suggest that this species can tolerate anoxic conditions. In experiment KTY14/00, one of the selected plots was saturated due to poor maintenance of drains in the area. However, planted birch were still c. 8 m high, and there was also some colonisation by willow in the same area.

Crop nutrition

It should be stressed that foliage samples were only collected if a crop was suspected to have nutrient deficiencies based on visual symptoms. Therefore, the results presented in Table 3 should be interpreted with caution. In addition, the site in Derrybrennan did not receive application of K as prescribed. There were also areas of the demonstration plots (CLE1/99 and KTY 1/99) which appeared to have received very little, if any fertiliser at all.

Nutrient analysis shows that P, in particular, was deficient in most samples taken (74%, Table 3). Although K deficiency was detected in only 7.7% of samples, more than half had marginal K levels. These low P and K values are mainly associated with peat depth and aeration (see Table 4), but other factors, such as the lack of appropriate timing and rates of fertilisation application or uneven application of fertiliser, may also have contributed to the poor nutrient status of the crops on some sites.

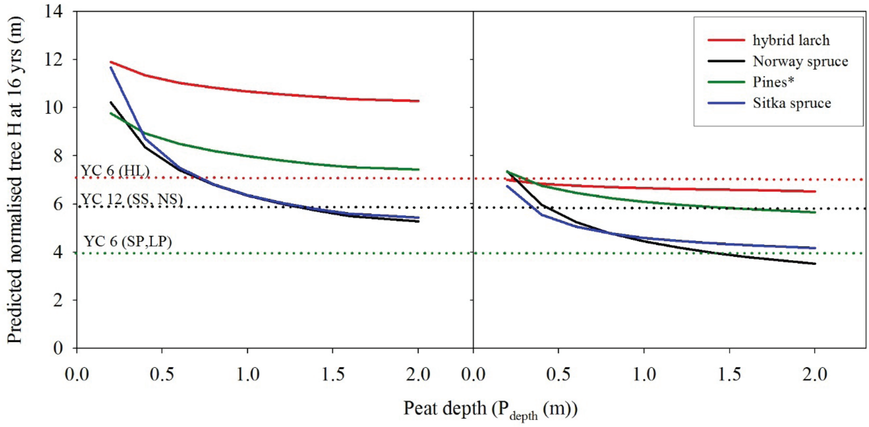

Figure 4: *Fitted model curves (Eq. 4) for tree H of different species over the peat depth range (solid coloured lines) under a well-drained (left panel,* $P_{aeration}$ *= 1) and poorly drained scenario (right panel,* $P_{aeration}$ *= 0.5). The segmented lines represent the indicative cut-off point for suitability (based on YC) of Norway spruce (NS, black), Sitka spruce (SS, black)), YC <12, hybrid larch (HL, red), lodgepole (LP, green) and Scots pine (SP, green), YC <6 (YC thresholds as used in the CLIMADAPT model (Ray et al. 2009)).*

Nitrogen deficiencies were detected in 12% of the samples taken. Low N in Killinagh could be associated with competition for N by *Calluna* on *Sphagnum* dominated peat plots. There were only three samples taken from this demonstration area.

Pearson's correlation analysis, presented in Table 4, provides some evidence to suggest a mechanistic reason for the poor performance of some conifer species on deeper and poorly aerated peats. The significant and negative Pearson's coefficient for the relationship between needle K content (Ln(K)) and P_{depth} for Norway spruce confirms that needle K deficiency is likely to occur in deeper peats. Although the same trend was observed for Sitka spruce and Scots pine this was not significant, possibly due to a limited number of sample plots (degrees of freedom were low). The significant positive correlation between needle K and P content and relative aeration ratio ($P_{aeration}$) also suggests that P uptake was limited under anoxic conditions leading to deficiencies in K and P. This may also have been partly caused by die-back in fine roots as previously reported for spruce under very wet conditions (Coutts 1982). This relationship was, however, not significant in some cases, such as for needle P content and P aeration for Norway spruce.

Discussion

These findings challenge the current recommendations for establishing conifer species, in particular Norway spruce, on cutaway peats of depths greater than 0.6 m (Jones and

Table 3: *Summary of nutrient status of crop samples from different experiments/trials, expressed as a percent of samples taken from each species in each experimental/demo nstration area that were deficient in N, P or K, based on threshold values published by Renou-Wilson et al. (2008).*

Experiment/Demo area	Species	% Deficient N	P	K
CLE 1/99	Norway spruce	0.0	90.9	9.1
CLE 2/00	Scots pine	0.0	100.0	0.0
	Sitka spruce	50.0	50.0	0.0
Derrybrennan	Norway spruce	0.0	0.0	66.7
Killinagh	Norway spruce	66.7	0.0	0.0
KTY 1/99	Norway spruce	0.0	100.0	0.0
KTY 16/00	Hybrid larch	0.0	100.0	66.7
	Norway spruce	0.0	100.0	0.0
	Scots pine	0.0	0.0	0.0
	Sitka spruce	75.0	75.0	0.0
KTY 17/00	hybrid larch	0.0	100.0	0.0
TLM 35/96	Scots pine	0.0	100.0	0.0
	Sitka spruce	0.0	100.0	0.0
Total		**12.3**	**73.8**	**7.7**

Table 4: *Pearson's regression coefficients for the relatio nships between peat depth or relative aeration ratio and the natural log of % nutrient content for nitrogen (N), phosphorous (P) and potassium (K). Coefficients highlighted in bold indicate that the relatio nship was significant at p <0.05(a) or p <0.01(b); ns mea ns that the relatio nship was not significant, based on the Pearson's correlation coefficient and the degrees of freedom (N-1).*

Species	Peat character	Nutrient Ln(N)	Ln(P)	Ln(K)	Deg. of freedom
Norway spruce	P_{depth}	0.08 ns	0.22 ns	**-0.39**[a]	36
	$P_{aeration}$	-0.12 ns	-0.12 ns	**0.41**[a]	36
Sitka spruce	P_{depth}	0.15 ns	-0.53	-0.36	6
	$P_{aeration}$	-0.49 ns	**0.92**[b]	0.59	6
Scots pine	P_{depth}	0.55 ns	-0.62 ns	-0.44 ns	7
	$P_{aeration}$	-0.66 ns	**0.96**[b]	**0.74**[a]	7

Farrell 2000). In contrast, our results, and publications from Scandinavia (Pietiläinen et al. 2005; Paavilainen and Päivänen 1995), suggest that peats as shallow as 15 cm (Figures 2 and 4) are more suitable for afforestation so long as drainage is sufficient to ensure suitable root aeration. Although the type of underlying calcareous material did not appear to influence tree growth, trees generally grew better on weathered calcareous material than calcareous mud deposits. In addition, it should be noted that no shell marl material was detected in any of the sample plots across the experimental sites.

Preliminary results from the BOGFOR project also reported a similar relationship between peat depth and aeration and tree performance (Renou-Wilson et al. 2008), however these authors did not investigate the different response of various species.

This study demonstrates a clear difference in how the five species that were investigated responded to variations in peat depth and aeration. In general, Sitka and Norway spruce should be confined to peats of less than 1.2 m under well-drained conditions. However, if drainage is not good (i.e. aeration ratios of less than 0.5), the peat depth should not exceed 0.3 to 0.5 m for these two species. Hybrid larch is very productive on deep peats (even up to 2 m), but does not tolerate poor drainage. In addition, current phytosanitary restrictions due to the outbreak of *Phytophthora ramorum* limit the use of hybrid larch on all site types, including cutaway peatlands. Birch, Scots pine and lodgepole pine are the only species examined which are suitable for peats deeper than 1.2 m and where sufficient drainage may be difficult to maintain. However, it is generally recommended to limit afforestation to gravity drained cutaway industrial peatland sites and to exclude areas prone to flooding in the winter months (Renou-Wilson et al. 2008).

The physiological reason for the decline in tree growth associated with peat depth and aeration is not clear, but regression analysis against major macro nutrients (Table 4) suggests that this may be related to nutrient deficiencies associated with either anoxic conditions (which limit the uptake of nutrients such as P or K) or increased leaching of P or K as peat depth increases (OCarroll 1966, Pietiläinen et al. 2005, Aro 2000b). Retention of nutrients, as a function of cation exchange, is generally expected to decrease in upper levels of deep peat, compared to shallower peats and regions of the profile close to the calcareous material. There was no evidence of P or K deficiency in foliar samples taken from these sites at year 5 (Renou-Wilson et al. 2008). In addition, the observed decline in leader growth in the last 4 to 5 years, particularly on deeper or poorly aerated peats, suggested that nutrient deficiencies were only manifested in deep peats after 10-16 years. Previous studies have indicated that other factors may be influencing growth on deep peats. For example, OCarroll (1966) suggested moisture deficiencies and cracking of peat under drier condition may be a contributing factor. Some of the Norway spruce and Sitka spruce on deep, well-drained peat bays in the current study did show symptoms of stress (prolific flower production). A decline in spruce productivity under anoxic conditions has also been reported to be associated with an increase in fine root mortality (Coutts 1982) and permanent decline in photosynthesis activity of needles under prolonged waterlogged conditions (Black et al. 2005).

The fact that most crops showed a deficiency of one or more macronutrients suggests that the current recommendation for nutritional management on cutaway peatlands needs to be reconsidered. Renou-Wilson et al. (2008) recommended fertiliser application for establishment with rock phosphate (12.5% P) in a split application: 175 kg ha^{-1} (21 kg P ha^{-1}) manually applied in bands in the year of planting and the same amount, manually broadcast, two years later, together with 250 kg ha^{-1}

of muriate of potash (50% K). The low level of phosphorus present in the foliage samples was indicative of the inadequacy of the rates of fertiliser phosphorus used in both the experiments and demonstration areas to sustain a satisfactory growth pattern. A significant falloff in phosphorus levels in particular, and nitrogen and potassium, after 8 to 10 years was also noted in the BOGFOR report (Renou-Wilson et al. 2008). These were in areas treated with either 600 kg of 0-10-20 or 350 kg of unground rock phosphate (42 kg P) and 250 kg of muriate of potash (125 kg K) at planting time. These rates are also significantly lower than those recommended in Finland. Re-fertilisation is generally carried out in Finland using PKB-fertilizer (some crops on cutaway peatlands show boron (B) deficiencies), with P in the form of apatite or wood ash (Paavilainen and Päivänen 1995, Kaunisto and Aro 1996). K fertilization is also recommended to be repeated about 15 years after planting (Pietiläinen et al. 2005), when broadcast fertilisation was applied at time of establishment. OCarroll (1966) reported severe K deficiencies in Norway spruce and Scots pine in a drained *Phragmites* peat site in the Irish midlands that had been under grass for a number of years prior to afforestation and that both species responded well to re-fertilisation.

Another nutrition management issue of concern is that there was evidence of a possible lack of adherence to fertiliser recommendations ("operational drop off"), particularly in larger demonstration areas. In some cases, it was questionable if some areas received any fertiliser at all, despite how suitable industrial cutaway peatlands are for mechanised application of fertilisers. Intensive monitoring should be carried out during and after establishment to ensure even spread and correct dose of application. Furthermore, the nutritional status of the crop should be closely monitored, and a third application may be required to ensure productivity is maintained up to canopy closure of the crop.

In conclusion, it is difficult to establish what proportion of the potential Bord na Móna area (16,000 to 20,000 ha) would be suitable for productive conifer plantations based on the information provided in this study. Recent analysis on three peat production areas surrounding the Edenderry power-plant estimated that, if production were to stop in 2023, only 22 to 42% of the peat areas would have a peat depth threshold of 2 m or less (Black et al. 2017). These areas may further reduce because it is not possible to uniformly harvest peat to a set level due to undulation of the underlying peat layer if the "Peco" extraction method is used (Black et al. 2017). Although alternative extraction methods, such as the "Haku" method[1], can be used to harvest to a more uniform peat depth, this production method is more expensive.

[1] The Peco method (from the old Russian *Peko* model) is used over large distances where peat depth may vary post-production. It involves the extraction of peat from the surface (in a horizontal plane) in the course of a number of passes, at a rate of c. 10 cm per year This method also results in a large stock pile of peat being left on a bay after production has ceased. In contrast, the Haku method can be used on smaller areas, so peat depth is more uniform post-harvest. In addition, the harvested peat is removed completely from site.

It is therefore likely that large areas of industrial cutaway peats (e.g. where peat depth is greater than 2 m and composed of *Sphagnum* peat) would not be suitable for forestry. The future configuration of industrial cutaway peatlands are likely to comprise a mosaic of wetland habitats, grasslands, short rotation coppice, peatland restoration areas, woodlands, forest plantations (for both timber and biomass) and new alternative land uses, such as windfarms or solar energy facilities. In 2016, Bord na Móna published a strategy which includes a large increase in the generation of renewable energy - through wind, solar projects and biomass supply. The company predicts an increase in biomass energy demand from 0.3 million tonnes in 2015 to 2.7 million tonnes by 2030 (Bord na Móna 2017). Forestry clearly has a role to play in meeting this demand, but the afforestation potential on cutaway peatlands appears to be much lower than was previously estimated.

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References
Aro, L., 2000. Root penetration of Scots pine and silver birch on cutaway peatlands. In *Proceedings of the 11th International Peat Congress,* Quebec, Canada. Eds. Rochefort, L. and Daigle, J.-Y. International Peat Society, Jyväskylä, Finland, pp. 932- 936.

Black, K, Davis, P., Mc Grath, J., Doherty, P. and Osborne, B. 2005. Interactive effects of irradiance and water availability on the photosynthetic performance of *Picea sitchensis* seedlings: implications for seedling establishment under different management practices. *Annals of Forest Science* 62(5): 413-422.

Black, K, McNally, G., Carey M. and Keane, M. 2017. *Assessment and update of species and related trials on industrial cutaway peatlands with a view to afforestation*. COFORD, Dublin.

Bord na Móna Annual Report. 2017. Available at http://www.bordnamona.ie/wp-content/uploads/2017/07/4558_BNM_AR17_ENG_Spreads.pdf [Accessed June 2017].

Coutts, M.P. 1982. The tolerance of tree roots to waterlogging. V. Growth of roots or Sitka spruce and lodgepole pine in waterlogged soil. *New Phytologist* 90: 467-476.

Hytönen, J. and Kaunisto, S. 1999. Effect of fertilization on the biomass production of coppiced mixed birch and willow stands on a cutaway peatland. *Biomass and Energy* 17(6): 455- 469.

Jones, S. and Farrell, E.P. (Eds.). 2000. *Research Programme to Develop a Forest Resource on Industrial Cutaway Peatland in the Midlands, BOGFOR 3 Project, Final Report*. Report No. 52, Forest Ecosystem Research Group, Department of Environmental Resource Management, University College Dublin, Dublin, Ireland, pp 145.

Kaunisto, S. and Aro, L. 1996. Forestry use of cutaway peatlands. In *Peatlands in Finland.* Ed. Vasander, H., Finnish Peatland Society, Helsinki, Finland, pp. 130-134.

Matthews, R.W. and Mackie, E.D. 2006. *Forest Mensuration: A Handbook for Practitioners*. Forestry Commission, Edinburgh, p. 330.

OCarroll, N. 1966. Growth check in Norway spruce and Scots pine due to potassium deficiency. *Irish Forestry* 23: 36-41.

Paavilainen, E. and Päivänen, J. 1995. *Peatland Forestry - Ecology and Principles.* Ecological Studies 111. Springer Verlag, Berlin.

Pietiläinen, P., Moilanen, M. and Vesala, H. 2005. Nutrient status and growth of Scots pine (*Pinus sylvestris* L.) on drained peatlands after potassium fertilisation. *Souseura - Finnish Peatland Society* 56(3): 101-113.

Ray, D., Xenakis, G. and Black, K. 2009. Developing a site classification system to assess the impact of climate change on species selection in Ireland. *Irish Forestry* 66: 101-123.

Renou-Wilson, F., Keane, M., McNally, G., O'Sullivan, J. and Farrell, E.P. 2008. *Developing a Forest Resource on Industrial Cutaway Peatland: The BOGFOR programme.* COFORD, Dublin, pp 176.

Svensson, J., Hånell, B. and Magnusson, T. 1998. *Naturlig beskogning av utbrutna torvmarker genom insådd från omgivande skog - Tree and shrub colonization of abandoned peat winning fields by seeding from adjacent forests.* Rapport 78. Rapporter i skogsekologi och skoglig marklära, institution för skoglig marklära, Swedish University of Agricultural Sciences, Uppsala, Sweden, p. 45.

The potential impact of intensification on forest productivity under different climate change scenarios

Alba Cabrera Berned[a*] and Maarten Nieuwenhuis[a]

Abstract

The intensification of forest management, using fast-growing species well-adapted to future climate conditions is seen as a solution to guarantee a sustainable increase in the domestic timber production, while avoiding or minimising any risks associated with climate change. This paper reports on the findings of a research project that assessed the productivity of Sitka spruce (*Picea sitchensis*) on a range of site types under different climate change scenarios and stand density control methods (i.e. planting spacings and thinning intensities). To this end, an integrated approach was developed through a link between the Irish dynamic yield models (Growfor) and the CLIMADAPT software, the Irish Ecological Site Classification System.

The results show that Sitka spruce is likely to produce yield class 14 or greater in most of Ireland by the end of the century, although its growth rate is expected to decrease in many parts of the country, especially in the south-east and some areas in the western regions, and alternative species may have to be used there. In general terms, stands planted at close spacings (1.7 m square) and thinned at light intensities (60-80% of marginal thinning intensity (MTI)), using a 5-year thinning cycle, would produce the greatest volume. When the management objective was to maximise the profitability rather than yield, applying light thinning intensities (up to the MTI) and planting a 3 m square was the best approach.

Keywords: *Growfor, CLIMADAPT, Sitka spruce, intensive forest management, climate change.*

Introduction

Demand for wood fibre in Ireland already exceeds the capacity of Irish forests to supply it and it has been forecasted to further increase by 40% by the end of the decade, much of this coming from the expanding bioenergy sector (COFORD 2011). However, strong pressure to support conservation, agriculture and housing may limit the land available for future afforestation plans to meet the increased demand for wood (COFORD 2016). According to Farrelly and Gallagher (2015), only 0.43 million ha of wet grassland and unimproved land have real potential for afforestation plans in Ireland. At the same time, future climate conditions, which will be marked by higher temperatures, changes in precipitation patterns and an increase in the frequency

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of extreme events (Dunne et al. 2008), are expected to impact on the way forests develop and the goods and services they can provide (Ray et al. 2008). Under these circumstances, the intensification of forest management practices, using fast-growing species well-adapted to the future climate conditions has been advocated as a solution in order to sustainably increase the domestic supply of raw material (Binkley 1997, Sedjo and Botkin 1997).

This study focused on Sitka spruce, which is the most important species of Irish forestry (accounting for 52.4% of the total forest estate according to the latest National Forest Inventory (NFI) in 2012) and the main pillar of the wood processing industry, due to its suitability to a wide range of climatic and edaphic conditions, its rapid growth rate and the versatility of its wood.

Intensive forest management

Intensive commercial forest management, undertaken on small existing and newly afforested areas in a sustainable and resilient manner, is seen as a possible solution to the increasing demand for wood fibre without the use of much more land. Concentrating timber production on the best-suited and adapted sites, where high growth rates can be achieved in the shortest possible time, requires a smaller amount of land to meet the demand for forest products and may allow large areas of forest to be given priority for other uses (e.g. biodiversity, protection and recreation) (Fox 2000).

This project focused on the increase in timber production through the intensification of forest management using stand density control methods, such as the initial planting, spacing and thinning intensity. The amount of growing space available to an individual tree will affect not only the size, shape and structure of its stem and its branching characteristics, but also the growth of the stand through the rate of site utilisation (Joyce and OCarroll 2002). Since the 1960s, several spacing, respacing and thinning studies in coniferous crops have been carried out in Ireland to examine the effect of growing space on tree and stand characteristics (Gallagher 1980, Gallagher 1985). Research has shown that close spacing results in inter-tree competition and high mortality, displaying slower tree diameter growth, longer rotations and lower rates of return (Thornhill 1956). High stocking densities also increase planting and operational costs and, as there is more root and crown competition, the dangers of windthrow, especially after thinning (Cremer et al. 1982). Wider spacings, on the other hand, allow trees to grow more rapidly and guarantees greater crown development leading to larger individual tree dimensions in a shorter period. This rapid growth of trees is offset by a reduction in the potential total volume production (Joyce and OCarroll 2002) and affects many timber characteristics (Moore et al. 2009). Close spacing promotes good clean stems with reduced side branching and knottiness, higher timber density, elasticity and tensile strength, resulting in high-quality timber (Simic et al. 2016).

Thinning treatments are an effective way to accelerate tree growth, reduce mortality and increase overall timber yield. They also increase the overall timber revenue by increasing the volume production of sawlog and provide a periodic income for the owner. The thinning influence on the volume growth varies with thinning intensity, frequency of thinning and, to a lesser extent, the length of rotation (Hummel 1957).

Traditionally, empirical growth and yield models have been the principal modelling tools used by foresters to make decisions on initial establishment spacing, when and how heavy to thin and the rotation length. Broad and Lynch (2006) developed a dynamical yield modelling system to represent forest growth in Ireland called Growfor. Growfor is used in Irish forestry to forecast the outcome of a wide range of silvicultural practices in terms of user-defined thinning regimes and different initial spacings (McCullagh 2013).

Climate change and forestry

Forests are particularly sensitive to climate change because the long lifespan of trees does not allow for rapid adaptation to a rapid rate or large magnitude of environmental change (Lindner et al. 2010, Keenan 2015). Higher temperatures, changes in precipitation patterns and rising atmospheric CO_2 concentrations are expected to have a significant effect on tree growth rates (Lindner et al. 2010). These climatic changes will indirectly increase the biotic and abiotic disturbances, which not only impact on forest productivity (Cannon 1998, Parmesan 2006) but may also initiate changes in species composition and forest structure and shifts in vegetation distribution (Keenan 2015).

The forecasted changes in the Irish climate over the 21st century (Dunne et al. 2008) will be marked by rising temperatures (increasing by up to 3.4 °C towards the end of the century), especially in the south and east of Ireland, and autumn and winter seasons will become wetter, with precipitation increasing by 15-25% towards the end of the century. On the other hand, summers are expected to become drier, with a 10-18% decrease in precipitation towards the end of the century. Projections suggest that the climate will become more variable, with an increased risk of storm damage and flooding.

In sustainable forest management, it is of fundamental importance to ensure that the tree species selected for a specific site are suited to the site conditions. CLIMADAPT, a multi-factor forest site classification system, which brings together climatic and edaphic factors that influence tree growth, is used in Ireland for guidance on species choice according to site type and future climate change scenarios (Ray et al. 2009).

Materials and methods

Effect of climate change on growth

CLIMADAPT was used to assess Sitka spruce suitability and yield in 100 sites around Ireland under current and future climates. The sites included in this study were selected randomly from the permanent forest sample plots used in the second cycle of the NFI (provided by J. Redmond, Forest Service 2017). In order to facilitate the analysis of CLIMADAPT outputs, the sites have been arranged in 7 geographical sub-divisions based on the Regional Authorities Establishment Order, 1993: East Coast, South-East, South-West, Midlands, West, Mid-West and Border.

For each selected site, CLIMADAPT stand analysis was performed using the system's default soil characteristics (SMR and SNR) and for four climate change scenarios: baseline (period 1961-1990), 2050 A2, 2050 B1 and 2080 A2. The future climate data (for the years 2050 and 2080) used in CLIMADAPT were calculated based on projections of the future greenhouse gas emissions scenarios A2 and B1 (SRES) described by the Intergovernmental Panel on Climate Change (IPCC) (Ray et al.2009). The output of the system provides an indicative yield class (YC) for each species/site combination and indicates whether a particular species is Very Suitable (YC >20), Suitable (YC 14 to 20) or Unsuitable (YC <14).

To assess the sensitivity of the results to the default soil assumptions built into CLIMADAPT, the modelling was also carried out for the 12 plots located in the South-East region, but using accurate soil data obtained from the NFI.

Effect of forest management on timber yield and revenue

The indicative yield class provided by CLIMADAPT was applied to typical regimes in the 1981 Forestry Commission Yield Tables (Edwards and Christie 1981), defined by the top line of each table (consisting of age, top height, mean DBH, stocking and BA). These top line data were the inputs required to run the simulations by Growfor. Growfor was used in this research project to analyse the volume production obtained under different forest management regimes and to analyse the income associated with the production of different assortments.

Greatest volume production

The simulations were carried out for each yield class from YC 10 to YC 24. The goal was to identify the management regime that produced the maximum cumulative volume to 7 cm top diameter. Thinning intensity was defined in terms of the marginal thinning intensity (MTI) which is the maximum intensity which can be maintained without causing loss of volume production. The British Forestry Commission (FC) models are based on the assumption that MTI equals 70% of the respective YC

(Edwards and Christie 1981). For this study, thinnings were controlled by the intensity of the volume reduction (expressed as a percentage of MTI) and the thinning cycle. A 5-year thinning schedule was adopted as the default. The thinning yields were calculated as a product of thinning intensity, YC and thinning cycle. The rotation lengths were based on the maximum mean annual increment (MMAI). When this point was reached, the maximum cumulative volume production was determined.

The potential production of timber in Sitka spruce stands was determined under the following scenarios:

- Thinning intensity: Heavy (120% MTI), Marginal (MTI i.e. 70% of MMAI), Light (80% MTI), Very Light (70% MTI), Super Light (60% MTI) and No thinning.
- Square spacing between trees: 1.7 m, 2 m, 2.4 m and 3 m.

The age of first thinning in each case, which was the earliest age at which thinning could take place without losing cumulative volume production, was based on Table 2 (average growing stock levels) in the Forestry Commission Booklet 48 (Edwards and Christie 1981). As the Forestry Commission models and Table 2 of Booklet 48 are based on stands thinned at MTI, it was necessary to interpolate these average growing stock levels for the other thinning intensities considered in this study.

Corrections to thinning intensity to account for the slow down of stand growth with age have not been included in order to keep the analysis manageable.

Greatest revenue

Growfor was also used to assess the harvest revenue based on the assortment production for YC 10 to YC 24. The same forest management regime in terms of thinning intensity, planting spacing and 5-year thinning cycles as described in the previous section, have been considered in the financial approach. In this analysis, the goal was to identify the management scenarios that maximise the profit based on short-term standing assortment prices (Table 1).

The Growfor model provides the assortment volume production for any age of the stand as well as the thinning yields. By applying the assortment prices to these volumes, the total revenue (main crop and thinnings) was calculated. The discounted

Table 1: *Timber assortment defined by small end diameter (SED) and large end diameter (LED) and their standing prices (2015).*

Assortment	**SED** (cm)	**LED** (cm)	**Price** (€ m^{-3})
Pulpwood	7	14	6
Palletwood	14	20	8
Small sawlog	20	24	32
Large sawlog	24	>24	41

Source PTR Ltd., 2015.

revenue (DR) for the main crop and thinning yields was calculated using a standard discount rate of 5%. To present the forest management's profitability, the net present value (NPV) was quantified. The NPV represents the net costs and revenues incurred throughout the rotation, expressed at current value. For the aim of this research, only the establishment cost differences were considered, it was assumed that other costs did not differ significantly between scenarios (as the analysis was based on standing prices). In determining the NPV, the standard investment formula for a timber stand with some modifications was applied (Eq. 1).

$$\text{NPV} = -C_0 + \sum_{n=0}^{N} \frac{V_n}{(1+r)^n} + \frac{H_N}{(1+r)^n} \qquad [1]$$

where:
C_0 = initial investment (i.e. the establishment costs);
V_n = value of thinning removal in n years' time;
H_N = value of clearfell in N years' time;
r = interest rate expressed as decimal;
n = the year number;
N = life of the project;
$1/(1 + r)^n$ = the discount factor.

Finally, to allow comparisons between the profitability of the different forest management alternatives (with different rotation lengths), the NPV was expressed by its equivalent annual value (NAE), see Eqs. (2) and (3). For each management regime, the maximum NAE and the age at it which occured (optimal rotation length) were determined.

$$\text{NAE} = \text{NPV} \times \text{Annuity factor} \qquad [2]$$

$$\text{Annuity factor} = \frac{r\,(1+r)^n}{(1+r)^n - 1} \qquad [3]$$

where:

NAE= net annual equivalent;
NPV= net present value;
r = interest rate expressed as decimal;
n = the year number;
$1/(1 + r)^n$ = the discount factor.

Harvest residue production

The revenue obtained for each forest management regime when including residual biomass harvesting into the financial analysis was also estimated. To determine the residual biomass production in each scenario, biomass expansion factors (BEFs) were used. These are multiplication factors used to expand merchantable tree stem volumes to account for non-merchantable biomass components (Tobin and Nieuwenhuis 2007).

The BEFs were calculated on the basis of 2002 survey data from managed Sitka spruce forests in Ireland (supplied by B. Tobin, UCD 2016). The data used to construct them consisted of the biomass content of the tree components (live and dead branches, tip and stem) and the correspondent DBH of a series of harvested trees. Equation 4 was used to calculate single tree level BEFs:

$$\text{BEF} = \frac{\text{Aboveground biomass (branches and tip)}}{\text{Timber biomass}} \quad [4]$$

The BEFs were arranged in five DBH groups and the average BEF for each group was calculated. The first DBH category started at 10 cm, as thinnings start to take place at an early stage in the stand growth simulations. Based on the study by Tobin and Nieuwenhuis (2007), which determined that BEF values are close to constant for DBHs greater than 30 cm, all stands with an average tree DBH exceeding 30 cm were included in the same group. The corresponding BEF values for each DBH group were: 10-15 cm: 1.48; 15-20 cm: 0.49; 20-25 cm: 0.44; 25-30 cm: 0.41; 30 cm and above: 0.37.

The revenue obtained from selling the residual biomass assortment was calculated by applying a standing price of €4.30 m^{-3} (D. Little, pers. comm. November 2016) and the NAE for each scenario was estimated. As the biomass price has not been long established in Ireland, the financial analysis was also run using double and triple the biomass price to assess NAE trends of scenarios with higher future biomass prices.

This assessment was carried out considering that all residual biomass was removed from site and sold after thinning and final clearfell operations. The impacts of making this material unavailable as a brash mat to support harvesting machinery and the impact of the loss of nutrients on future stand development were not evaluated. The amount of brash available to be sustainably removed from a site for biofuel markets will depend on the soil type and other site factors, marketing opportunities and restocking objectives (Moffat et al. 2006), and this practice should only be carried out on sites where such risks have been evaluated by the forest manager.

Results

Effect of climate change on growth

CLIMADAPT simulations for the baseline period showed that Sitka spruce was well-suited to the prevailing Irish climatic conditions and was capable of growing at YC 14 or greater in most of Ireland (97%) and YC 20 or greater in 67% of the territory. The mean YC at a national level was estimated at 20 m^3 ha^{-1} yr^{-1} and the most productive regions appeared to be located in the Border, West and Mid-West of Ireland, achieving YCs greater than 20. Limitations to the growth in the baseline scenario were mainly due to the species' sensitivity to moisture deficits (MD), the strong winds affecting the south-west of the territory and the poor soil conditions where they occurred.

When Sitka spruce suitability and productivity were examined under medium and long-term future climate change scenarios, CLIMADAPT indicated that the species was likely to continue to be suitable and productive by the middle (in 84% of the territory in scenario B1 and 70% in scenario A2) and the end of the century in the majority (66%) of the country, for the medium-high carbon emission scenario A2. However, the predicted changes in the climate and site quality are likely to greatly affect the species growth rate, reducing its productivity, on average, by up to 5 YCs at a national level over the course of the current century (Table 2). By the end of the century, the main limiting growth factors predicted by CLIMADAPT will be MD and soil moisture regimes.

The areas more likely to suffer from droughts, where the MD was predicted to increase over the course of the present century, will become less favourable for the growth of Sitka spruce. The areas most affected were located along the south-east coast of Ireland, where Sitka spruce growth could be reduced on average by up to 6 YCs by 2080 (becoming unsuitable with productivity levels lower than YC 14). The productivity of Sitka spruce plantations in the north-west, west and south-west of Ireland were predicted to decrease considerably, on average by up to 5 - 7 YCs. In this case, the main reasons behind the forecasted reduction were the very wet conditions (i.e. waterlogging of the soil), combined with poor soil quality and effect of strong winds that were expected to occur in the long-term scenario.

Although the vast majority of plantations where Sitka spruce is grown are expected to experience a decrease in the growth rate by the end of the century, areas where growth factors other than temperature will not be limiting will experience the maintenance or an increase in the productivity of Sitka spruce forests. These areas are located in some parts of the Midlands and inland parts of the western regions.

When running the simulations using detailed soil data from the NFI as inputs in CLIMADAPT, no big differences in average YC were found in the South-East region compared to the results obtained using the default soil characteristics. The same average YC (16) was forecasted for the baseline scenario under both methodologies, although an increase of one to two YCs was predicted for the mid and long-term scenarios when considering more accurate soil data. This analysis also indicates that Sitka spruce is likely to be suitable in this region by 2050 (average YC 14 under the climate change scenario A2 and YC 17 under the scenario B1), although its productivity might be reduced by up to 5 YCs by the end of the century, resulting in it being no longer suitable in the region (YC 11 on average). The slight increases in

Table 2: *Sitka spruce productivity (average YC) forecasted for three scenarios (2050 B1, 2050 A2 and 2080 A2) and compared with the current baseline, for the seven geographical regions considered in the study. The reduction in productivity by the end of the century for the 2080 A2 scenario in comparison to the baseline was also included.*

Scenarios	Ireland total	East coast	South-east	South-west	Mid-lands	West	Mid-west	Border
Baseline	20	19	16	21	18	21	21	22
2050 A2	16	18	12	16	15	17	19	16
2050 B1	18	20	16	17	18	19	20	16
2080 A2	15	16	10	14	14	18	16	17
Reduction by 2080 A2	5	3	6	7	4	3	5	5

YC were a result of an improvement in the soil conditions when using NFI soil data.

Effect of forest management on timber yield and revenue

Greatest volume production

All YCs showed higher cumulative volume production when stand thinning was lighter than at MTI. The volume of timber removed when using the MTI was too large for the stands to recover after the thinning and resulted in the reduction of potential volume production for all YCs. These reductions were greater as the thinning intensity (120% MTI) and the spacing between trees increased, indicating that sites were not being fully utilised.

For low YCs (10, 12 and 14), the light thinning (80% MTI) and very light thinning (70% MTI) intensities were the ones that guaranteed the highest cumulative volume, whereas the super light and unthinned treatments resulted in a reduction in volume production. However, when higher YCs were considered (i.e. YC 16 to 24), the volume of timber removed in each thinning operation was larger than in smaller YCs and lighter thinning intensities, such as super light thinning intensity (60% MTI) achieved the objective of producing the maximum cumulative volume, especially when wider spacings were considered (Figure 1).

The results reflect a significant effect of initial spacing on the growth and volume production of stands. The overall productivity of a stand was lower in widely spaced stands than in closer spaced ones. It was also noticeable that the actual total harvest volume for the lighter thinning scenarios did not differ very much for low and high YCs, although the rotation lengths needed to produce these volumes were quite different. Obviously, rotations for the same cumulative volume were considerably shorter when the YCs were higher, regardless of the forest management regime, signifying higher volume production in the same amount of time.

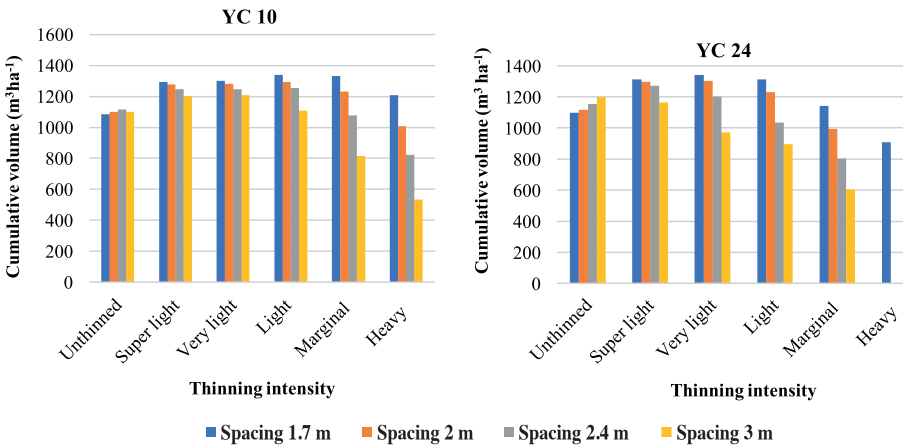

Figure 1: *The effect of different thinning intensities and planting spacings on maximum cumulative volume for yield class (YC) 10 and 24, in Sitka spruce stands. Note: where cumulative volume values are not represented in the graph it is because the Growfor simulations could not be completed (i.e. final stocking in the stand was too low or thinning yield was too high).*

Greatest revenue

The highest net annual revenue achieved in each scenario was determined according to assortment production and prices. Thinned stands were more profitable than unthinned ones as they produced higher proportions of more valuable larger timber when clearfelling and because of the contribution that early thinnings made to the present value. Stands that had been planted at wide spacings, which required lower establishment costs than higher stocking rates, produced larger timber quicker and, therefore, resulted in greater income over the rotation. No big differences were found between stands thinned at different intensities. However, in the higher YCs, the marginal and heavy thinning intensities were too severe for stands, resulting in a reduction of the timber volume production and, therefore, also a drop in the associated net discounted revenue. The stands thinned up to marginal thinning intensities generally generated higher NAEs. However, for lower YCs (for example, YC 14 and 16), the introduction of more intense thinnings resulted in the higher production of large sawlog and associated higher income, especially when the stands were planted at close spacings. The analysis indicates that it is not worth planting Sitka spruce forests on sites that cannot achieve at least YC 14; lower YCs would result in economic losses. The results indicate that the scenario which guaranteed the greatest revenue was planting at 3 m square spacing and applying very light or light thinning intensities (Figure 2).

In unthinned stands, less sawlog but higher proportions of pulp and pallet wood (which could potentially be used as energy wood) were produced. Similarly, low YCs produced more volume of smaller assortments than high YCs, and consequently less volume of larger timber.

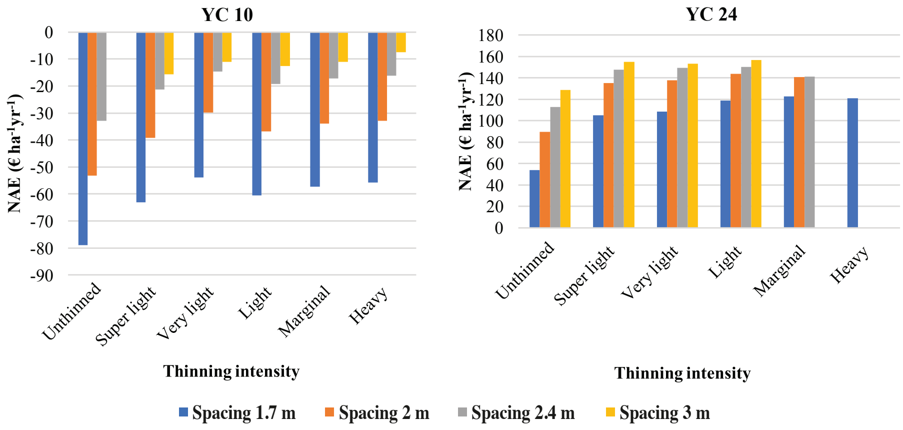

Figure 2: *Maximum NAE based on tree assortments, for Sitka spruce yield class 10 and 24, under different management scenarios. A 5% discount rate was applied.*

When residual biomass production was included in the simulations, the results showed that close spacings produced higher residual biomass volumes than wider ones (Figure 3). The overall volume production increased by about 200 m^3 ha^{-1} in unthinned stands and 300 m^3 ha^{-1} for thinned scenarios, for all YCs. However, as the biomass price per cubic metre is still very low in Ireland, its inclusion in the financial analysis results in an increase of only around €20 per year for high YC and about €10 annually for lower YCs. Although close spacings produced more volume of biomass material, wide initial spacings still resulted in greater net revenue for most of the thinning treatments and YCs, because the establishment costs were much lower for wide spacings. However, it is noticeable that the annual income for 2.4 m and 3 m square spacing was almost similar for most YCs when the stand was thinned. In higher yield classes, especially for light and heavier thinning intensities, the NAEs for 2 m square spacing was close to the net annual income when planting was at wider spacings.

Discussion

Effect of climate change on growth

According to both the NFI and CLIMADAPT outputs for the baseline scenario, Sitka spruce is currently growing at high growth rates in Ireland (YC 20 on average). However, climate change forecasts for the end of the century indicate that climate in Ireland will be marked by higher temperatures and changes in precipitation patterns (Dunne et al. 2008), resulting in significant effects on Sitka spruce growth rates. The changing climatic conditions will impact differently on Sitka spruce growth depending on the change between the old and new site characteristics, mainly on the level of water availability.

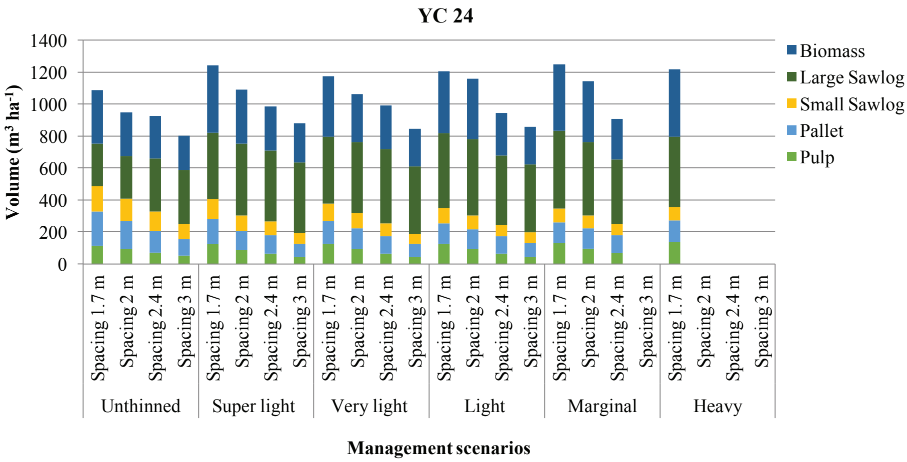

Figure 3: *Volume production per assortment, including harvest residues, over the financial rotation of YC 24 Sitka spruce stands, under different management scenarios.*

Cameron (2015) indicated that Sitka spruce requires a relatively high soil moisture status for good growth, together with an annual precipitation typically around 1,000 mm or higher. A dendroclimatological study, conducted on Sitka spruce in Avoca (Co. Wicklow), showed that large reductions in radial growth were associated with MDs above 180 mm (Tene et al. 2009). However, the maritime climate of the country and the fact that Sitka spruce has largely been confined to soils with high water storage capacity or soils with high seasonal water tables (Farrelly et al. 2009) explain why MDs have rarely been encountered in plantation forestry in Ireland. Nevertheless, extended and frequent drought periods are expected in central, southern and east-coastal parts of the country, especially in summer, increasing to more than 7 droughts per decade towards the end of the century (Dunne et al. 2008, Ray 2008). Actually, the baseline scenario indicated that Sitka spruce planted along the south-east coast is already growing at medium growth rates (YC 16 on average) because of limitations in water availability. The future increases in temperature, evapotranspiration levels and summer MD levels expected in this area will reduce its productivity by up to 6 YCs by the end of the century. This indicates that the species will no longer be suitable on sites in the southeast with freely draining soils (and high MDs). Most of the sites in the midlands and along the east coast will also be sensitive to a future drier climate and are likely to experience, but to a lesser extent than the southeast, a reduction in timber yield by 2080.

Although the increase in warmth (when moisture, nutrients or other growth factors are not limiting) is expected to positively affect forest productivity (Cannell 2002, Black et al. 2010), CLIMADAPT only predicts a slight increase or a maintenance of Sitka spruce productivity in some inland sites in the western regions. A study carried out by

Tene et al. (2009) indicated no significant relationship between temperature and Sitka spruce growth in Ireland and the UK. Therefore, the improvement in water availability in these few areas in the west seems to be a factor behind the forecasted increase in Sitka spruce yield.

Most of the areas located in the south-west, west and north-west coast of Ireland will experience a drastic decline in productivity because of the increase in moisture in the soil expected over the next number of decades. The soils located in these areas are expected to experience waterlogging conditions by the middle and end of the century. Different field studies have shown a reduction in Sitka spruce growth when growing in environments with excess water - in wet and very wet soil moisture regimes (Coutts and Philipson 1978, Farrelly et al. 2011).

The default soil characteristics in CLIMADAPT are based on a model that uses a soil map as the basis and, as a result, are only indicative. However, as this study aimed to assess general trends in the country, focusing on the average productivity class obtained in different regions, the system's default soil characteristics were considered sufficient. Nevertheless, to assess the sensitivity of the outcomes based on the default soil characteristics, the simulation was repeated using NFI soil data for the plots located in the South-East region. This additional analysis was carried out for this area not only because it was considered to be the most sensitive region to the potential impact of climate change, but also because the results obtained using the default options differed from the results found in another study (Farrelly et al. 2009) which identified higher productivity rates in this region due to more favourable soil qualities for Sitka spruce. When running the simulation using more accurate data, no big differences were found in the forecasted YC for Sitka spruce compared to those obtained using the default settings, especially in the long-term scenario. Despite the small differences in the results, to provide the most robust predictions of growth, the use of CLIMADAPT in further analysis of the impact of climate change on the productivity of the Irish forest estate should be based on field data (obtained during a site visit by identifying soil type, topography, local management practices and carrying out vegetation surveys).

The influence of other factors, such as CO_2 fertilisation, nitrogen deposition, or other secondary effects of increasing temperatures (e.g. pests and diseases and forest fire) may also affect Irish forest productivity (Ray et al. 2008). However, these factors have not been included as variables in CLIMADAPT because it is still not clear how they interact with the main climatic and soil quality variables used in the model predictions.

The warmer and drier climate that is predicted for the end of the century in Ireland may offer the possibility of extending the range of species that are currently less common in Irish plantations, especially in areas where Sitka spruce is likely not to grow sustainably at higher rates. Diversifying tree species and increasing the genetic diversity of the forests may be a strategy to cope with climate change impacts (Mason et al. 2012, Pawson et al. 2013, Cameron 2015).

Effect of forest management on timber yield and revenue

Growfor models were used to simulate the effect of different management regimes to identify the scenario that produced the greatest volume production and revenue. As the stand growth and production are determined by the models, it is important to be aware of their compatibility. First of all, the Forestry Commission yield tables and Growfor models are not based on the same dataset. In addition, the climate and typical forest treatments applied to the research plots in Ireland are not identical to those in Britain. McCullagh et al. (2013) concluded that Growfor generally forecasts significantly lower volumes than those in the Forestry Commission yield tables for different species growing in Ireland, but Sitka spruce deviated from the main trend. Gallagher (1972) showed that the volume in unthinned Irish Sitka spruce stands was greater than the figures displayed in the Forestry Commission yield tables, which supports the view that Sitka spruce volumes forecasted by Growfor were close to those predicted in the Forestry Commission tables (McCullagh et al. 2013). Broad and Lynch (2006) carried out extensive work to ensure the statistical validity of the Growfor models.

Greatest volume production

The simulations of volume production indicate that stands planted at close spacings and thinned at light to moderate intensities (60-80% of the MTI) result in the greatest volume production through the optimal utilisation of space on a site. It would not be recommendable to thin at MTI (70% of the respective YC) or at heavier intensities for any YC as this results in volume losses. This is consistent with results from a study conducted in Ireland which showed that the volume extracted when thinning Sitka spruce stands (YC 24) at the MTI was too large since the main crop that remained did not produce the maximum or even a sustainable volume increment (McCullagh et al. 2013).

Since the volume of timber removed in thinnings was fixed throughout the rotations, it may have resulted, in some cases, in a stocking reduction to a level that caused a loss of cumulative volume production. In some cases, when applying high thinning intensities in understocked stands, more volume was removed than the remaining stand could sustainably support. Such cases resulted in Growfor terminating the simulation (because of low stocking projections). In practice, the specified thinning yields are intended for use with fully stocked stands and reductions in yields are necessary for stands that are understocked (Rollinson 1988).

On the other hand, results from this study also indicate that leaving a stand unthinned would reduce the volume production through inter-tree competition and mortality. Similar results were found in a thinning intensity experiment in Sitka spruce stands (YC 24) established at Avoca forest, Co. Wicklow, which indicated that the greatest volume production was achieved when stands were thinned at a moderate intensity (55% of the MTI removed), whereas the unthinned stands accounted for the greatest reduction in volume because of the restricted growing space (Joyce and OCarroll 2002).

This analysis demonstrates a significant effect of initial spacing on the growth and volume production of stands. The overall productivity of thinned stands was lower in widely spaced stands than in closer spaced ones (with an opposite trend for unthinned stands). Producing similar results, a respacing experiment established in Baronscourt, Northern Ireland, in Sitka spruce plantations (YC 20) indicated a sharp decline in total crop volume for stocking densities lower than 1,450 stems ha^{-1}, with greatest total volume production when planting at densities between the two closest spacings (2,900 and 1,450 stems ha^{-1}) (Joyce and OCarroll 2002).

Greatest revenue

The financial analysis was based on the NPV, which represents the net costs and revenues incurred throughout the rotation, expressed in today's money. Results indicated higher financial returns when high YCs were considered, as they produced more valuable timber in shorter financial rotations (revenues discounted over shorter periods of time) than lower yield classes.

Thinned stands were more profitable than unthinned ones, as supported by several studies carried out in Ireland (Thornhill 1956, Joyce and OCarroll 2002), which show how thinned stands can produce a higher proportion of more valuable large timber when clearfelling than unthinned stands. Furthermore, thinning not only produces a periodic income starting early in a rotation, but also higher net present values, as the early thinning revenues are discounted over shorter periods of time than the clearfell revenue obtained from unthinned stands. Those stands that have been planted with wider spacings will also produce larger timber assortments quicker, reaching higher values over the rotation than those planted at close spacings. However, when the growing space available is not fully utilised, the rapid growth of trees may be offset by a loss in potential volume production, which explains why thinning at the MTI or heavier would result in lower volume production and reduced economic returns compared to lighter thinning intensities. Although the effect on timber prices due to changes in timber quality was not assessed in the analysis, it is important to keep in mind that wide planting spacing may also affect a number of intrinsic timber properties (i.e. straightness, larger branch and knot size, larger proportions of juvenile core and lower wood density, elasticity and tensile strength), which may result in lower quality timber (Simic et al. 2016, Moore et al. 2009) and a lower associated value.

When including harvest residues in the financial simulations (and not taking quality considerations into account), the stands thinned and planted at the widest spacing (3 m square) achieved the highest net revenue, even though higher harvest residue volumes were produced at the closer spacings. This is explained by the current low price associated with the biomass assortment in Ireland and by the higher establishment costs of planting at high stocking densities. Actually, when doubling and tripling the biomass price, the scenarios that resulted in greatest net revenue were planting at 2 m square spacing and by applying light or marginal thinning intensities. The commercialisation of clearfell harvest residues could become realistic in a natural regeneration scenario, where establishments costs would be greatly reduced.

Climate change and forest management

Future afforestation plans should result in new Sitka spruce forests on those sites where the species is forecasted to be suitable, producing high growth rates, considering the climate change expected to occur over the next decades.

In the previous sections, the optimal combinations of planting spacings and thinning intensities were identified for stable Sitka spruce stands. However, it may be necessary to adapt these practices to the specific site conditions to avoid timber volume and/or financial losses. For example, the prediction of stronger wind events expected for the next decades will especially affect Sitka spruce forests growing on soils with very high moisture regimes, which may render the trees unstable and susceptible to windthrow (Ray et al. 2008). Changes in forest management regimes and methods of site preparation, such as site drainage and mounding to prevent waterlogging and anaerobic conditions, have been shown to favour a stand's stability (Paterson and Mason 1999). Traditionally, no-thinning regimes were seen as a solution to increase stand stability as no gaps are created in the canopy, but as the results presented in this study indicate, stands left unthinned result in a drastic reduction in commercial volume production and in financial losses. Therefore, as suggested by other authors, stands growing on sites that present a windthrow risk should be thinned early, applying low thinnings and a short thinning cycle to provide enough growing space for the residual trees without creating major openings in the canopy (Joyce and OCarroll 2002). At the same time, close spacing also results in greater dangers of windthrow than wider spaced stands as there is more root and crown competition (Cremer et al. 1982). Equally, in regions where high MDs are forecasted for the next decades, reducing tree densities through silvicultural thinning is seen as a strategy for minimizing forest drought vulnerability as the soil moisture availability to the remaining trees of a stand is increased (D'Amato 2013) and because suppressed trees (in dense stands) become more vulnerable to damage caused by drought (Cameron 2015). A series of forest management recommendations have been developed from these considerations and are proposed as guidance for foresters on how to establish and thin Sitka spruce stands in Ireland, to either maximise volume production or revenue, under current and future climatic conditions (Table 3).

Table 3: *Forest management recommendations for Sitka spruce under current and future climate conditions, for different geographical regions in Ireland.*

Region	Time frame	Sitka spruce growth under climate change forecasts	Management recommendations
East-Coast and Midlands	Mid-term	Current high growth rates will be maintained or suffer a slight reduction by mid-century.	To maximise volume production, initial spacing of 1.7 m square and moderate to light thinnings (60-80% of MTI) on a 5-year cycle, managed on rotations of 60-65 years, should be applied. To achieve greatest revenue from the stand, initial minimum spacing of 2 m square and thinnings up to MTI for rotations of 40-45 years should be considered. Thinnings of 60% of MTI and a 3-year thinning cycle should be preferable in those stands located close to the east coast, which are exposed to higher windthrow risks.
	Long-term	Stands will continue to be productive although productivity may be considerably reduced, due to the increase in MD levels.	To reduce drought vulnerability, the reduction in tree densities through thinning (apply 80% of the MTI to get higher timber volumes or MTI to maximise the revenue) and planting at wider spacings (i.e. 2 m square spacing when the aim is to maximise timber yield, or 2.4m/3m square when maximizing profit and not taking quality into consideration) would be recommended.
South-East	Mid-term	Already growing at medium growth rates because of the presence of freely draining soils and limitations in water availability.	To ensure that more water is available for remaining trees, plantations should be thinned at the maximum thinning intensity possible without damaging the potential stand's productivity (80% of MTI) using rotations of 70-75 years, to reach the greatest volume production; or thinned to MTI and using rotations of about 50 years, to maximise profit.
	Long- term	The forecasted increase in drought episodes is likely to cause a great reduction in productivity (no longer suitable in the region).	When establishing new forest plantations, replace Sitka spruce with other species that are more drought tolerant or, when possible, to plant mixed species stands.
Western regions	Mid-term	Current high productive classes, which will be slightly reduced by mid-century.	Stands currently growing in these regions should be thinned at moderate to very light thinning intensities (60% -70% of MTI), especially on those sites with high risk of windthrow, and managed using rotations of 60-65 years if the aim is to get the greatest volume production, or 40-45 years if the aim is to maximise revenue.
	Long- term	A dramatic drop in productivity is expected (especially in the South-West), due to a large increase in soil moisture.	Stands (re)established on soils with poor drainage should be planted at wide spacings (2.4 2/3.0 m square), thinned at super light thinning intensities (60% of MTI) and thinned on a 3-year cycle, to reduce the risk of windthrow. As the YC is expected to be lower in the future, longer rotations will be necessary to maximize volume production or revenue. Intensive methods of site preparation (i.e. drainage and mounding) and/or planting other species more suitable to the new climate conditions, should be considered.
		Some inland sites where growth factors will be less limiting, may experience a maintenance of or increase in productivity.	More intensive practices, such as closer planting spacings and heavier thinning intensities (80% of MTI) may be adopted, using shorter rotations (less than 40 years to achieve maximum income).

Conclusions and management recommendations

This study revealed that the future climatic conditions in Ireland are likely to impact on Sitka spruce growth rates. The species is expected to continue to be suitable in the vast majority of the country, but its productivity levels will be significantly reduced at a national level over the course of the present century and some regions will become less favourable for its growth (i.e. the south-east of Ireland and the western regions). Therefore, even applying more intense management may not lead to increased production. It also appears that current management, based on 2 m square spacing and thinning less than MTI, is close to optimal so little gain can be made. Overall, a reduction in timber output can be expected.

This research has demonstrated that to maximise both production and revenue from stable Sitka spruce stands, foresters should apply thinning to 60 - 80% of MTI for most YCs. No thinning or thinning to MTI or heavier would result in reduced volume production. When assessing the optimal planting spacing, the overall productivity was lower in widely spaced stands than in closer spaced ones, although the financial analysis indicated higher profits, not taking changes in timber quality into consideration, when wider spacings were considered.

To adapt the Irish forest estate to climate change and to guarantee a sustainable development, forest management practices should be adapted to the new climate and soil conditions. To this end, a series of forest management recommendations have been proposed to guide foresters on how to establish and thin Sitka spruce stands in Ireland (see Table 3). The recommendations should only be used for guidance and a site visit, the use of risk assessment models and an analysis of the timber market are suggested before deciding which silvicultural practices to apply.

References

Binkley, C.S. 1997. Preserving nature through intensive plantation forestry: the case for forestland allocation with illustrations from British Columbia. *Forestry Chronical* 73: 553-559.

Black, K., Xenakis, G. and Ray, D. 2010. Climate change impacts and adaptive strategies. *Irish Forestry* 67: 66-85.

Broad, L. and Lynch, T. 2006. Growth models for Sitka spruce in Ireland. *Irish Forestry* 63: 53-79.

Cameron, A.D. 2015. Building Resilience into Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests in Scotland in response to the threat of climate change. *Forests* 6: 398-415.

Cannell, M. 2002. Impacts of climate change on forest growth. In *Climate Change: Impacts on UK Forests*. Ed. Broadmeadow, M.S.J., Forestry Commission Bulletin 125. Forestry Commission, Edinburgh, UK.

Cannon, R.J.C. 1998. The implications of predicted climate change in the UK, with emphasis on non-indigenous species. *Global Change Biology* 4: 785–796.

COFORD Roundwood Demand Group. 2011. *All Ireland Roundwood Demand Forecast 2011-2020*. COFORD, Department of Agriculture, Food and the Marine. Dublin, Ireland.

COFORD Land Availability Working group. 2016. *Land Availability for Afforestation. Exploring Opportunities for Expanding Ireland's Forest Resource*. COFORD, Department of Agriculture, Food and the Marine. Dublin, Ireland.

Coutts, M.P. and Philipson, J.J. 1978. Tolerance of Tree Roots to Waterlogging. I. Survival of Sitka Spruce and Lodgepole Pine. *New Phytologist* 80: 63-69.

Cremer, K.W., Borough, C.J., McKinnell, F.H. and Carter, P.R. 1982. Effects of stocking and thinning on wind damage in plantations. *New Zealand Journal of Forestry Science* 12: 244-268.

DAFM. 2013. *The Second National Forest Inventory - Republic of Ireland - Results*. Department of Agriculture, Food and the Marine. Dublin, Ireland.

D'Amato, A.W., Bradford, J.B., Fraver, S. and Palik, B.J. 2013. Effects of thinning on drought vulnerability and climate response in north temperate forest ecosystems. *Ecological Applications* 23: 1735-1742.

Dunne, S., Hanafin, J., Lynch, P., McGrath, R., Nishimura, E., Nolan, P., Venkata Ratman, P., Semmler, T., Sweeney, C., Varghese, S. and Wang, S. 2008. *Ireland in a Warmer World- Scientific Predictions of the Irish Climate in the Twenty-First Century*. Community Climate Change Consortium for Ireland (C4I). Dublin, Ireland.

Edwards, P. and Christie, J. 1981. *Yield Models for Forest Management*. Forestry Commission Booklet 48.

Farrelly, N., Ní Dhubháin, Á., Nieuwenhuis, M. and Grant, J. 2009. The distribution and productivity of Sitka spruce (*Picea sitchensis*) in Ireland in relation to site, soil and climatic factors. *Irish Forestry* 66: 51-73.

Farrelly, N., Ní Dhubháin, Á. and Nieuwenhuis, M. 2011. Modelling and mapping the potential productivity of Sitka spruce from site factors in Ireland. *Irish Forestry* 68: 23-40.

Farrelly, N. and Gallagher, G. 2015. The potential availability of land for afforestation in the Republic of Ireland. *Irish Forestry* 72: 120-138.

Fox, T.R. 2000. Sustained productivity in intensively managed forest plantations. *Forest Ecology and Management* 138: 187-202.

Gallagher, G. 1972. Some patterns in crop structure and productivity for unthinned Sitka spruce. *Irish Forestry* 29: 33-52.

Gallagher, G. 1980. Crop structure studies in Ireland. In Growing space in coniferous crops, Supplement to *Irish Forestry*. *Irish Forestry* 37: 5-32.

Gallagher, G. (Ed). 1985. *The Influence of Spacing and Selectivity in Thinning on Stand Development, Operations and Economy*. Proceedings of the meeting of IUFRO Project Group P.4.02.02. Dublin, Ireland. 24 – 28 September 1984. Forest and Wildlife Service: 108-113.

Hummel, F.C. 1957. Yield regulation and forecasts of production. *Irish Forestry* 14: 100-107.

Joyce, P. and OCarroll, N. 2002. *Sitka Spruce in Ireland*. COFORD, Department of Agriculture, Food and the Marine. Dublin, Ireland.

Keane, T. and Collins, J.F. 2004. *Climate, Weather and Irish Agriculture*. 2nd ed. AGMET, Met Eireann, Dublin.

Lindner, M., Maroschek, M., Netherer, S., Kremer, A., Barbatie, A., Garcia-Gonzalo, J., Seidl, R., Delzon, S., Corona, P., Kolström, M., Lexer, M.J. and Marchetti, M. 2010. Climate change impacts, adaptive capacity, and vulnerability of European forest ecosystems. *Forest Ecology and Management* 259: 698-709.

Local Government Act. 1991. *Regional Authorities, Establishment Order, 1993*. Dublin, Ireland.

Mason, W.L., Petr, M. and Bathgate, S. 2012. Silvicultural theories for adapting planted forests to climate change: from theory to practice. *Journal of Forest Science* 58: 265-277.

McCullagh, A., Hawkins, M., Broad, L. and Nieuwenhuis, M. 2013. A comparison of two yield forecasting methods used in Ireland. *Irish Forestry* 70: 7-17.

Moffat, A.J., Jones, W.M. and Mason, W.L. 2006. *Managing Brash on Conifer Clearfell Sites*. Forestry Commission Practice Note 13. Forestry Commission, Edinburgh.

Moore, J., Achim, A., Lyon, A., Mochan, S. and Gardiner, B. 2009. Effects of early re-spacing on the physical and mechanical properties of Sitka spruce structural timber. *Forest Ecology and Management* 258: 1174–1180.

Parmesan, C. 2006. Ecological and evolutionary responses to recent climate change. *Annual Review of Ecology, Evolution and Systematics* 37: 637–669.

Pawson, S.M., Brin, A., Brockerhoff, E.G., Lamb, D., Payn, T.W., Paquette, A. and Parrotta, J.A. 2013. Plantation forests, climate change and biodiversity. *Biodiversity and Conservation* 22: 1203–1227.

Paterson, D.B. and Mason, W.L. 1999. *Cultivation of Soils for Forestry*. Forestry Commission Bulletin 119. Forestry Commission, Edinburgh.

Ray, D. Xenakis, G. Semmler, T. and Black, K. 2008. The impact of climate change on forests in Ireland and some options for adaptation. In *Proc. from COFORD Conference Forestry, Carbon and Climate Change- local and international perspectives*, pp 23-34.

Ray, D., Xenakis, G., Tene, A. and Black, K. 2009. Developing a site classification system to assess the impact of climate change on species selection in Ireland. *Irish Forestry* 66: 101-122.

Sedjo, R.A. and Botkin, D. 1997. Using forest plantations to spare natural forests. *Environment* 39: 14-20.

Simic, K., Gendvilas, V., O'Reilly, C., Nieuwenhuis, M. and Harte, A. 2016. The effects of planting density on the structural timber properties of 23-year-old Irish-grown Sitka spruce. Paper presented at the Civil Engineering Research in Ireland (CERI 2016) conference. Galway, Ireland.

Tene, A., Tobin, B., Ray, D., Black, K. and Nieuwenhuis, M. 2009. Adaptability of forests species to climate change. *TRACE (Tree Rings in Archeology, Climatology and Ecology)* 8: 62-68.

Thornhill, J.J. 1956. Planting spacings. *Irish Forestry* 12: 68-70.

Tobin, B. and Nieuwenhuis, M. 2007. Biomass expansion factors for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Ireland. *European Journal of Forest Research* 126: 189-196.

A characterisation of eucalyptus short rotation forestry plantations in Ireland

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Abstract

This paper details the characterisation of the biomass for use as a wood fuel of fifteen eucalyptus plantations (including twelve *Eucalyptus nitens* stands, two with *E. gunnii* and one with *E. delegatensis*) being grown on a short rotation in Ireland. Two of the plantations were mature (22 and 23 years old), while 13 of the plantations were more recently established (5 to 7 years old). Mortality rates were high, ranging from 11% to 62%. Trees were sampled and analysed for moisture content, ash content, calorific value, chemical composition (C, H, N, Cl, S) and ash melting behaviour. A biomass expansion factor was developed from the sample tree data to estimate total aboveground biomass from merchantable biomass and total height. Productivity on the measured sites ranged between 0.4 – 12.6 odt (oven dry tonnes) ha^{-1} yr^{-1} of aboveground biomass. The chemical composition analysis indicated that the eucalyptus trees tested had higher than typical values for chlorine content for bark, branch, tops, and foliage partitions, as quoted in EN14961-1, which may be problematic for some biomass boilers. Tests carried out on ash melting behaviour indicated that the wood and branch partitions have a low ash melting point. The results are somewhat limited, as the eucalyptus plantations in Ireland currently are either less than 10 years of age, or over 20.

Keywords: *Renewable energy, wood fuel characteristics, biomass partitions, biomass expansion factor.*

Introduction

The Department of Agriculture, Food, and the Marine (DAFM) recently implemented a new Forestry for Fibre scheme which aims to promote the planting of forests which can provide a clearfell crop within 10 – 15 years (DAFM 2015). The management objectives of such forests are to produce fibre material for use primarily in the panel board and wood energy markets rather than for sawn timber. This scheme, in combination with the Agro-forestry scheme, has a target of planting 3,300 ha by 2020. A clear distinction is made by this grant scheme not to include short rotation coppice or fast-growing trees that have a rotation of less than 10 years between harvests. The scheme is therefore supporting single-stem forests that will have stem dimensions larger than woody multi-stemmed energy crops such as willow coppice.

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This type of forest silvicultural system is referred to as Short Rotation Forestry (SRF) (Christersson and Verma 2006). The DAFM scheme supports a number of species including eucalyptus.

Legal obligations specified in the European Renewable Energy Directive (European Directive 2009/28/EC) set goals for Ireland to produce at least to 16% of all energy consumption from renewable sources by 2020. SRF could potentially help Ireland achieve this target, which will contribute to achieving energy security as well as protection of the environment through a reduction of greenhouse gas emissions.

In Europe, SRF has become increasingly attractive due to the increased demand for biomass (Johansson and Karačić 2011). Over 10 million m^3 of eucalyptus wood is consumed in southern European countries each year (DIEF 2000). Interest in the genus is also increasing in more northern countries. A recent study by Leslie et al. (2012) on the potential for eucalyptus as a wood fuel in the UK concluded that "the interest in using biomass as a source of energy has provided a catalyst for the re-examination of the potential role of eucalyptus in short rotation forestry in Britain". The British Forestry Commission have identified that eucalyptus in particular can produce biomass at a faster rate than many other species. Kerr (2011) reported that *Eucalyptus glaucescens* (Maid. and Blakeley) can produce 2.5 – 7.6 odt ha^{-1} yr^{-1}, and *E. gunnii* (Hook. f.) can produce 1.5 – 8.2 odt ha^{-1} yr^{-1} in the UK. This has been echoed in Ireland by Thompson et al. (2012), who concluded that "eucalyptus can play a role in providing a source of fibre or fuel to help meet the current demands for this material in Ireland". Thompson et al. found that three 17-year-old *E. nitens* ((Dean and Main.) Maid.) plantations produced mean annual increments (MAIs) ranging from 26.2 – 32.0 m^3 ha^{-1} yr^{-1}, equating to 11.4 –13.9 odt ha^{-1} yr^{-1}, based on their reported basic wood density of 435 kg m^{-3}.

In order to describe the qualities of a species for use as a wood fuel, a number of further parameters are required. Basic density Basic density, the dry wood mass per unit volume, expressed in kg m^{-3} (Thygesen 1994) is an important wood fuel characteristic, as it describes the amount of wood present per unit volume. The calorific value describes the energy content of the biomass per unit mass. The gross calorific value assumes that all water created in the combustion process is condensed and the heat of enthalpy is recovered (Serup and Kofman 2005). The net calorific value accounts for the loss of energy from the enthalpy of the water produced in the combustion. It is calculated using the hydrogen, nitrogen, and oxygen contents of the fuel (EN 14918: 2009). When the net calorific value and basic density are known, the energy content of any quantity of fuel at any moisture content can be calculated. The ash content of biomass is the inorganic, incombustible component. It is expressed as a percentage of the dry matter weight, % ash content on a dry basis (EN 14775: 2009). A high ash content means that less of the biomass is combustible as a fuel, and that there is more ash to be disposed of at the end of the combustion process. It is also important to characterise the ash melting behaviour as ash deposition may cause slagging and fouling of a boiler system (Coates et al. 2014). Slagging is the deposition of sticky, molten ash on the furnace walls and hottest parts of the boiler system which experience radiant heat transfer directly from combustion flames; fouling takes place in the relatively cooler parts of the system where flue gas and fly ash cool and form deposits, often on heat exchanger tubes. The chemical composition is important in the calculation of net calorific value, as described above. The chemical composition can also influence the usability of biomass as a fuel because of potential emissions and suitability for combustion under certain boiler configurations (Stam et al. 2009). Chlorine content is a concern for boiler operators, as high concentrations can cause corrosion of the boiler (SEAI 2004). Carbon, hydrogen and nitrogen are also important elements to quantify for carbon accounting purposes, as well as for life cycle analysis of biomass supply chains.

The objective of this paper is to characterise short rotation eucalyptus plantations in Ireland in terms of their survival, volume production and biomass dry matter production. In addition, the paper also describes estimates of wood fuel parameters such as calorific value, ash content, and ash melting behaviour – specific to various tree partitions. The concentrations of carbon, hydrogen, nitrogen, chlorine and sulphur are also reported. These parameters are known to be important characteristics of wood fuel allowing useful energy content to be described, and are also the characteristics which may limit their use under certain conditions.

Materials and methods

Spatial data were received from the Forest Service and Coillte GIS division to locate every eucalyptus plantation on record in Ireland. Information from previous publications was also used to identify older plantations. The data were filtered to identify sites five years and older. This was to ensure that the plantations visited were fully established. Within sites, areas were further stratified if considerable differences in height were apparent between stand areas. Each stratum was considered a separate site, and a full set of measurements were taken on each. Figure 1 displays the study site locations. Using British Forestry Commission inventory prescriptions (Matthews and Mackie 2006), between six and twelve plots were located in each study site depending on the area: 6 plots for sites of 0.5 – 2.0 ha, 8 plots for sites of 2 – 10 ha, and 10 plots or more for sites over 10 ha. The plots were located across the longest possible transect through each site. In each plot, the DBH of every tree was recorded, the total height of three trees were estimated using a digital hypsometer (Haglof Vertex IV Digital Hypsometer): the tree with largest DBH (for use in estimating top height), the tree whose DBH was closest to average, and the tree with smallest DBH[1]. In three plots per site, additional measurements were collected: for each of the three height trees, the base diameter, diameter at one third of total height and the height at 7 cm diameter were recorded with a Criterion (Lasertech Criterion RD1000), and the crown projection was measured using a densitometer (GRS Densitometer). In these plots, an ecological site classification of the sampling plots was carried out according to Ray et al. (2009). This involved the assessment of such parameters as soil type, soil water regime, and soil nutrient regime using a soil pit in each plot, and the identification of key indicator plants. The canopy cover at each site was estimated as a percentage of the ground area using a densitometer along three transects through the stand, as described by Geographic Resource Solutions (2016). The base diameter, DBH, upper stem diameter at one third total height, and height at 7 cm diameter were used with Smalian's formula to calculate timber volume. These data were used to develop a local basal area to merchantable volume equation (using a linear model) for each site. The equations were used with plot data to calculate merchantable volume per DBH measurement. The merchantable biomass for each DBH measurement was calculated by multiplying the merchantable stem volume by a basic density value obtained from felled sample trees (detailed below). The volume and biomass were summed in each plot to estimate the site totals.

On three sites, (one *E. delegatensis* (T.T. Bak.) site, and two *E. nitens* sites),

Figure 1: *Site numbers and locations of sampling sites. Asterisks mark sites where destructive sampling was carried out.*

[1] Inherent in this was the assumption that the tree had to have reached a minimum height of 1.3 m to have a DBH.

sample trees (n = 10 per site) were sampled to develop a biomass expansion equation which was applied to the other sites. Samples were also taken of tree partitions to characterise wood fuel parameters such as basic density, ash content, calorific value, chemical analysis and ash melting behaviour. The trees were felled by chainsaw. The total height, and the stem diameter at 1 m intervals up to merchantable height (7 cm diameter) were measured.

Sample trees were then partitioned into the following:

- stem: the wood and bark of the merchantable stem (≥7 cm diameter). This did not include branches.
- top: the wood and bark obtained from the un-merchantable stem section of the tree. This did not include branches.
- wood: the wood, free from bark of the merchantable stem.
- bark: bark only from the merchantable stem.
- live branches: wood and bark from live branches of the tree.
- dead branches: wood and bark from dead branches of the tree.
- foliage: leaves from live branches.

Disks were cut every three metres along the stem (Figure 2) and analysed for moisture content and basic density to estimate the biomass in the stem. The volume of the disks was determined by submersion in a water bath, and density was calculated as dry mass divided by green volume. The branches and tops were weighed, chipped on site with a Linddana TP200 chipper, and sampled for moisture content. For all partitions, the moisture content was determined by oven drying at 105 °C for 48 hours. The sample material from each partition from all trees was then mixed, divided and prepared to a particle size of less than 1 mm as set out in ISO 14778: 2011. For each of these mixed samples, ash content, expressed as percentage dry weight, was determined using a Carbolite muffle furnace at 550 °C, according to EN 14775: 2009. Gross calorific value was determined using a Parr 5500 oxygen bomb calorimeter, according to EN 14918: 2009. Carbon, hydrogen, nitrogen and sulphur content were measured using an Exeter Analytical CE 440 elemental analyser. Chlorine content was determined through a titrimetric method. Net calorific value was calculated from the equation in EN 14918: 2009:

$$NCV_{db} = GCV_{db} - 212.2 \times H - 0.8 \times (O + N) \quad [1]$$

where:

H = the hydrogen content, in percentage mass, of the moisture-free (dry) biomass (including the hydrogen from the water of hydration of the mineral matter as well as the hydrogen in the biofuel substance);

O = the oxygen content in percentage by mass, of the moisture-free biomass;

N = the nitrogen content, in percentage by mass, of the moisture-free biomass.

The wood fuel parameter data is presented in tables for each partition along with the values quoted as typical in the EN Solid Biofuel Standards. The sample tree data has been used with non-linear regression to parameterise a single tree merchantable biomass to aboveground biomass model.

Figure 2: *Sampling* Eucalyptus delegatensis*. This involved sectioning stems and cutting disks for analysis.*

Results

Local merchantable volume and merchantable biomass equations

Figure 3 illustrates the local single tree basal area (m^2) to single tree merchantable volume (m^3) function for each site. These relationships were used to calculate the merchantable volume for each tree where only a DBH measurement was taken.

DBH to total height equation

A DBH to total height equation was developed from measurements taken from a total of 305 trees. A Chapman-Richards model form was used, as per Coates et al. (2012). The model form is as follows:

$$Total\ height = 1.3 + \beta_1 \times \left[1 - \exp\left(-\beta_2 \times DBH\right)^{\frac{1}{\beta_3}}\right] \qquad [2]$$

where total height was estimated in metres and DBH in centimetres.

β_3 was set to 0.7, as per Coates (2012), as this gave a better fit when tested. The rest of the model was parameterised as follows: β_1 = 16.7116 (SEE 0.849), β_2 = 0.0478 (SEE 0.004). The function was also adjusted to localise to each sample plot by using the height and DBH of a tree per plot as inputs, as per Coates et al. (2012) as this allows the model to better predict for the other trees in the plot. Figure 4 illustrates the data and the fitted model. Using this equation, an associated height was estimated for every DBH measurement.

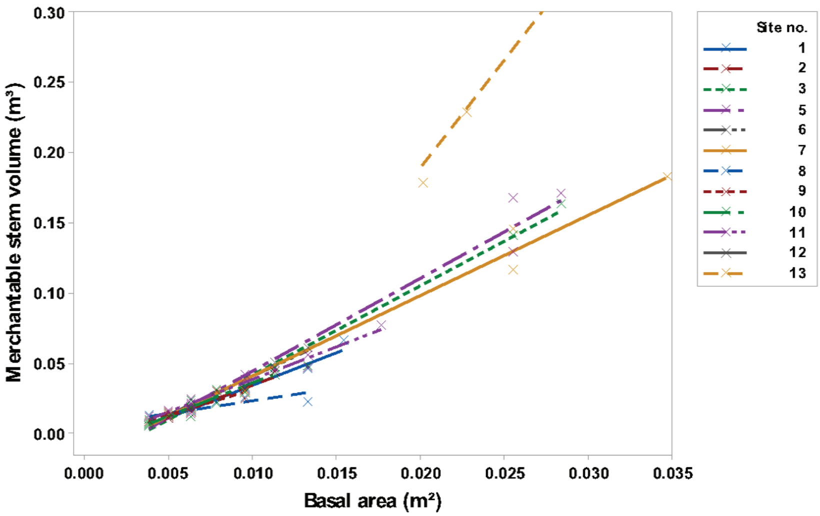

Figure 3: *Site-level single-tree relationships between basal area (m^2) and merchantable stem volume (m^3).*

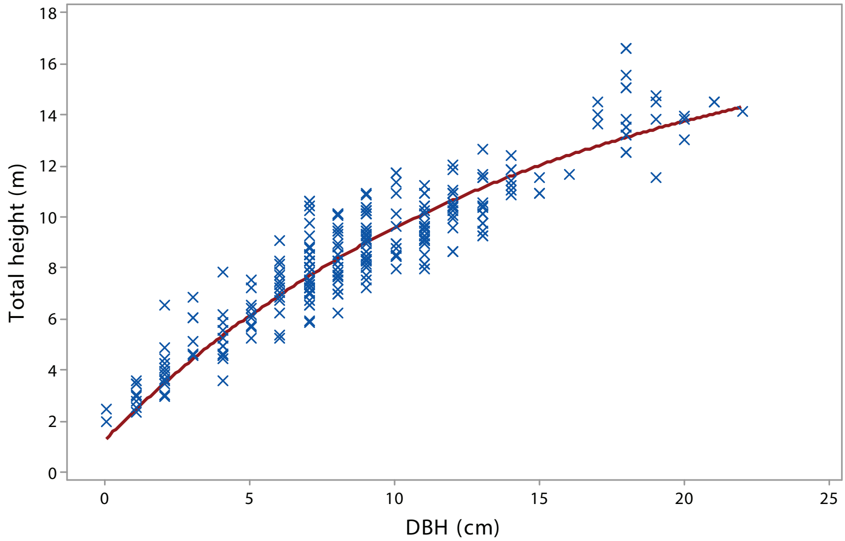

Figure 4: *Scatterplot of DBH (cm) and total height (m) fitted with a Chapman-Richards model.*

Single tree biomass expansion factor equation

A biomass expansion factor (BEF) is the ratio between merchantable stem biomass and total aboveground biomass. An equation to estimate single tree BEFs from total height was developed using regression analysis. A model form using the natural logarithm of tree height, as described by Levy (2004) for BEF modelling, was first fitted to the data. However, this model form was found to be unsuitable due to the limited range of the available data. Instead, an asymptotic convex model was fitted to the data using nonlinear regression. An asymptotic model form was chosen as the BEF cannot be less than 1, but should approach 1 as height increases and the stem forms an ever-larger proportion of aboveground biomass. The model form is as follows:

$$BEF = \beta_1 - \beta_2 \times \exp\left(-\beta_3 \times Total\ height\right) \qquad [3]$$

The asymptote (β_1) was estimated at a starting value of 1. The parameterisation of the model resulted in the following coefficients: β_1 = 1.07625 (SEE 0.027), β_2 = -12.6343 (SEE 3.603), β_3 = 0.2630 (SEE 0.0298). Figure 5 displays the data and fitted model. On each site, a BEF was calculated for every DBH measurement using the associated height estimate. This was then used to expand merchantable biomass estimates per tree to total aboveground biomass.

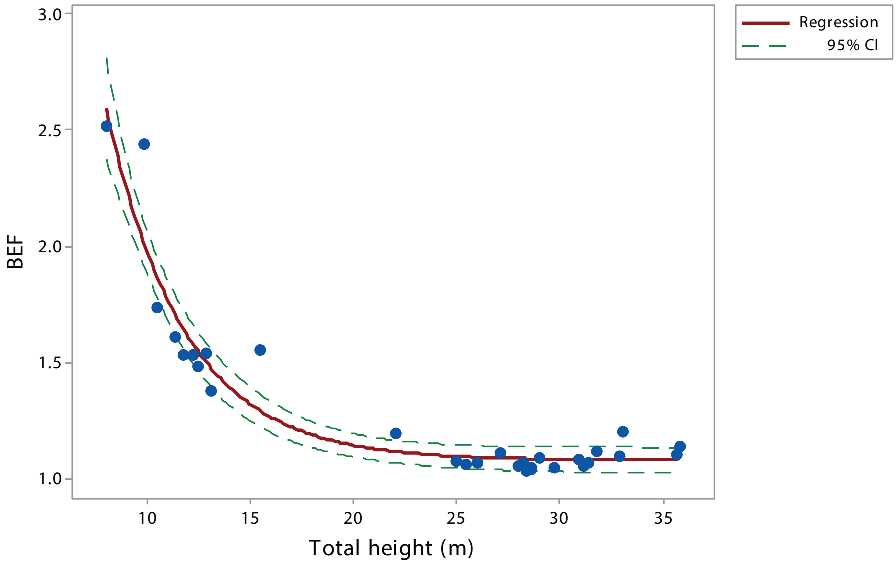

Figure 5: *Scatterplot of tree total height versus biomass expansion factor. The model fitted to the data was: BEF = 1.07625 + 12.6343 × e* $^{(-0.262992 \times \text{Total height (m)})}$.

Basal area to biomass equation

For trees which were less than 7 cm DBH, a separate formula was used to estimate their biomass. As these trees have no merchantable volume, a BEF cannot be used, so a direct relationship between basal area and aboveground biomass was formed from a small number of trees (n = 5). A simple straight-line equation explained the relationship with an R^2 of 98.1%. The equation of the model for estimating single tree aboveground biomass was as follows:

$$Aboveground\ biomass\ (dry\ kg) = 0.0305 + 2271 \times Basal\ area\ (m^2) \qquad [4]$$

Productivity Results

The sampling sites are described in Table 1 (including their ecological site classification), survival, top height and basal area. Fifteen sites were measured: twelve *E. nitens* sites, two *E. gunnii* sites, and one *E. delegatensis* site. It was found that the soil nutrient regime was poor to medium on all sites, and the soil moisture regime was dry to moist. The majority of the sites were five to seven years old, with two of the sites being more mature (22 and 23 years of age). All the stands visited had been established on reforestation sites. Tree mortality was relatively high, up to 62% mortality in the case of site number 4. The average mortality over all the sites was 28%. Even though the mortality was high for all younger plantations (5 – 7 years), only one standing dead tree was observed, indicating that mortality occurred early in the rotation. In the older plantations, 400 standing dead trees ha^{-1} were observed on site 13, while no data were recorded for site 12 due to windblow. Top height for the 7-year-old plantations ranged from 7 m to 13 m. The 22 and 23-year-old plantations had top heights of 28 m and 33 m, respectively.

Table 2 details the merchantable volume and biomass, residue biomass, and aboveground biomass estimates for all sites. Overall, the aboveground biomass productivity at the younger sites ranged from 0.4 odt ha^{-1} yr^{-1} to 6.4 odt ha^{-1} yr^{-1}. The most productive of these was site 5, which had 65 m^3 of merchantable standing volume after seven growing seasons. This equated to 27 odt ha^{-1} merchantable stem biomass. The quantity of (harvest) residues on this site were estimated as being 18 odt ha^{-1}. Therefore, the total aboveground biomass on the site was 45 odt ha^{-1}, indicating a productivity of 6 odt ha^{-1} yr^{-1}. The older sites had a productivity of 8.2 odt ha^{-1} yr^{-1} for site 12, and 12.6 odt ha^{-1} yr^{-1} for site 13.

The wood fuel parameters of the analysed partitions are detailed in Tables 3 and 4. Ash contents were higher than typically quoted wood biomass values for both stem and bark partitions. The ash content of the stem was 1.2%, slightly higher than the EN value range of 0.2% to 1.0%. The ash content of the bark was nearly twice the upper range of typical values quoted in EN literature at 5.7%. However, there was large variability in the samples, as reflected in the standard deviation. Gross and net calorific values for bark were lower than typical EN values, as would be expected from material with higher ash content. Contents of C, H, N, and O were as expected, with some small variability from typical values. Sulphur was also within the expected range for all partitions. Chlorine, however, was observed as being higher than the typical values for all partitions. The stem and wood partitions were both on average over twice the higher value of the typical range. The bark partition was observed as having a chlorine content of 0.34%, which is approximately seven times the typical EN value. The tops and live branches partitions were also approximately 6 – 7 times the typical EN value for residues. The foliage and bark were the two partitions with the highest concentrations of chlorine. The ash melting behaviour of the partitions, expressed as the mode of results, were all above 1,500 ^{o}C, except for the wood and the live branches partitions, which were both below 850 ^{o}C.

Discussion

Mortality was observed in all the study sites. On the 5- to 7-year-old sites, the percentage mortality ranged from 11 to 62%, with the average being 28%. There was no correlation between the canopy cover and the mortality, which was tested statistically

Table 1: *Soil, site and stand characteristics of the study sites. The tree species at sites 1 – 11 and 13 was E. nitens; site 12 was E. delegatensis and E. gunnii was growing at sites 14 and 15.*

Site (GS)[a]	Soil type[b]	Soil nutrient regime[c]	Soil moisture regime[d]	Elevation (m)	Surviving trees ha^{-1} (incl. <7 cm DBH)	Mortality (%)	Canopy cover (%)	Standing dead trees (n ha^{-1})	Stocking (trees >7 cm DBH)	Trees <7 cm DBH (n ha^{-1})	Top height (m)	Basal area (m^2ha^{-1})
1 (6)	BG/PG	P - M	F - M	189	1,600	36	43	0	1,330	270	10	9.9
2 (7)	LBE	M	M	168	1,414	43	44	0	771	643	9	5.3
3 (7)	LBE	M	M	173	1,863	25	66	0	1,250	613	13	11.3
4 (7)	BG	P - M	VM	168	950	62	22	0	210	740	7	1.1
5 (7)	LBE	M	M	169	1,400	44	48	0	1,213	187	13	14
6 (7)	LBE/BG	M	M	172	1,467	41	42	0	417	1,050	12	4.3
7 (7)	LBE	M	M	174	1,917	23	61	0	1,150	767	13	12.2
8 (7)	GI	P	SD	184	1,967	21	40	1	833	1,134	9	4.9
9 (7)	GBE/P	P	SD	151	2,217	11	53	0	1,100	1,117	9	6.1
10 (7)	GS	P - M	SD	171	2,100	16	52	0	1,138	962	10	7.7
11 (6)	PG	P	M	153	2,200	12	55	0	1,300	900	11	8.8
12 (22)	LBE	VP	MD	92	436	-	-	-	436	0	28	34.8
13 (23)	PG/SW	M	VM	180	842	-	-	400	842	0	33	49.8
14 (5)	PG	VP	M	223	2,200	12	25	0	0	2,200	5	NA
15 (5)	PG/SW	P - M	VM	243	1,783	29	36	0	67	1,716	6	0.28

[a] Growing seasons in brackets.
[b] Where BG is brown gley, PG is podzolic gley, LBE is loamy brown earth, GI is gravelly iron pan soils, GBE is gravelly brown earth, P is podzol, GS is gravelly, sandy brown earth and SW is surface water gley.
[c] Where VP is very poor, P is poor, VP is very poor.
[d] Where VM is very moist, M is moist, F is fresh, SD is slightly dry and MD is moderately dry.

Table 2: *Productivity estimates of the study sites.*

Site[a]	Age[b]	QMDBH (cm)	Average merchantable roundwood (m^3 per tree)	Merchantable roundwood (m^3 ha^{-1})	Stem basic density (kg m^{-3})	Merchantable stem biomass (odt ha^{-1})[c]	Residue biomass (odt ha^{-1})	Aboveground biomass (odt ha^{-1})	Productivity (aboveground biomass) (odt ha^{-1} yr^{-1})
1	6	11	0.02	31		13	15	28	4.7
2	7	10	0.02	15		6	12	18	2.6
3	7	11	0.04	44	412	18	16	34	4.9
4	7	8	0.01	2		1	4	5	0.7
5	7	13	0.05	65		27	18	45	6.4
6	7	12	0.04	18		7	9	16	2.3
7	7	12	0.04	50		21	17	38	5.4
8	7	9	0.02	13		5	13	18	2.6
9	7	9	0.01	16		7	15	21	3.0
10	7	10	0.02	23		9	15	25	3.6
11	6	10	0.02	30		12	17	30	5.0
12	22	32	0.88	385	435	167	13	180	8.2
13	23	27	00.8	666	394	262	27	289	12.6
14	5	0	0	0		0	0	2	0.4
15	5	8	0	1		0	0	5	1.0

[a] Species at sites: 1 – 11, 13: *E. nitens*; 12: *E. delegatensis*; 14, 15: *E. gunnii*.
[b] Growing seasons.
[c] Estimated using a basic density of 412 kg m^{-3} for site no.s 1-11, 14 and 15, 435 kg m^{-3} for site no. 12, and 394 kg m^{-3} for site no. 13.

Table 3: *Wood fuel parameters per tested partitions (standard deviations in parenthesis).*

Partition	Gross calorific value (GJ t^{-1})	Carbon content (%)	Hydrogen content (%)	Nitrogen content (%)	Chlorine content (%)	Sulphur content (%)	Oxygen content (%)	NCV (GJ t^{-1})
Stem	**19.2** (0.1)	**46.40** (2.77)	**5.70** (0.16)	**0.18** (0.10)	**0.08** (0.03)	**0.010** (0.017)	**46.41** (2.89)	**17.96**
Bark	**17.7** (1.4)	**46.09** (5.92)	**5.38** (0.46)	**0.40** (0.13)	**0.34** (0.05)	**0.017** (0.015)	**42.04** (2.03)	**16.56**
Wood	**19.4** (0.3)	**48.64** (2.54)	**6.12** (0.23)	**0.19** (0.04)	**0.07** (0.03)	**<0.01**	**44.48** (2.23)	**18.05**
Live branches	**19.9** (0.3)	**49.92** (2.11)	**5.85** (0.19)	**0.51** (0.09)	**0.14** (0.03)	**0.013** (0.015)	**41.39** (1.85)	**18.61**
Dead branches	**19.5** (0.1)	**48.51** (2.77)	**5.92** (0.31)	**0.32** (0.07)	**0.10** (0.10)	**0.007** (0.006)	**43.87** (3.18)	**18.21**
Tops	**20.1** (0.2)	**48.68** (3.66)	**5.97** (0.06)	**0.55** (0.40)	**0.13** (0.05)	**0.017** (0.029)	**42.25** (4.65)	**18.81**
Foliage	**22.4** (0.5)	**54.12** (3.42)	**5.92** (0.15)	**1.49** (0.14)	**0.22** (0.04)	**0.113** (0.042)	**34.54** (3.71)	**21.15**

Where Stem and Wood partitions refer to virgin materials with or without insignificant amounts of bark. Bark refers to virgin bark materials, and residues refers to virgin harvesting residues.
For reference, typical values are quoted from **EN14961-1** (including Gross Calorific Value (GCV) and Net Calorific Value (NCV) in MJ kg^{-1}, all other parameters on a percentage dry basis (db)):
Stem/Wood**;* Ash: 0.2 to 1.0, GCV: 19.4 to 20.4, NCV: 18.4 to 19.2, Carbon: 48 to 52, Hydrogen: 5.9 to 6.5, Oxygen: 41 to 45, Nitrogen: <0.1 to 0.5, Sulphur: <0.01 to 0.05, Chlorine: < 0.01 to 0.03. ***Bark; Ash: 0.8 to 3.0, GCV: 18.0 to 22.7, NCV: 17.1 to 21.3, Carbon: 47 to 55, Hydrogen: 5.3 to 6.4, Oxygen: 32 to 42, Nitrogen: 0.1 to 0.8, Sulphur: <0.02 to 0.20, Chlorine: <0.01 to 0.05. ***Residues*:** Ash: 2 to 10, GCV: 19.5 to 20.0, NCV: 18.3 to 18.5, Carbon: 50 to 51, Hydrogen: 5.8 to 6.1, Oxygen: 40 to 43, Nitrogen: 0.3 to 0.8, Sulphur: 0.01 to 0.08, Chlorine: <0.01 to 0.02.

Table 4: *Wood fuel parameters per biomass partition relating to ash content (standard deviation in parenthesis) and deformation.*

Partition	Ash content (% db)	Ash deformation					
		Init. deform. (°C)	Soften. (°C)	Hemisph. (°C)	Flow (°C)	Rs (°C)	Slagging potential
Stem	1.2 (0.1)	>1,500	>1,500	>1,500	>1,500	>1,500	Weak
Bark	5.7 (4.7)	>1,500	>1,500	>1,500	>1,500	-	Weak
Wood	0.5 (0.3)	<850	<850	<850	<850	-	Severe
Live branches	2.2 (0.4)	<850	<850	<850	<850	-	Severe
Dead branches	1.3 (0.5)	>1,500	>1,500	>1,500	>1,500	-	Weak
Tops	2.4 (0.6)	>1,500	>1,500	>1,500	>1,500	>1,500	Weak
Foliage	3.6 (0.6)	>1,500	>1,500	>1,500	>1,500	-	Weak

Init. deformation refers to initial deformation temperature, where the test piece shows the first signs of rounding due to melting. Soften. is the the softening temperature, where the height of the test piece is equal to its width. Hemisph. is the hemisphere temperature, where the test piece has melted sufficiently to form a hemisphere. Flow refers to the temperature where the test piece has effectively melted. Rs refers to the slagging index.

with regression analysis, which suggests that the mortality was not a response to light competition. There was also only one dead tree observed on any of these sites, indicating that the mortality had occurred either during or shortly after planting. The exceptional weather events of 2010, where temperatures fell below -12 ^{o}C in counties Waterford and Cork, could have contributed to the mortality. Another source of mortality may have been poor plant handling during establishment. According to the Forestry Programme 2014 – 2020, for grant aid purposes, the stocking of eucalyptus plantations must be maintained at a minimum of 80% over the ten years of premium payment. This was not achieved by nine out of the thirteen plantations, so they would not be eligible to receive premium payments due to mortality if they were planted as part of the Forestry for Fibre afforestation scheme. These mortality rates are likely to be affecting the productivity on the sites in some cases. However, as discussed by Thompson et al. (2012), the optimal stocking for volume production for eucalyptus in Ireland may lie somewhere between 1,800 and 2,000 plants ha^{-1}. Considering Thompson's recommendations, it may be the case that even with high mortality rates, the appropriate stocking level is being achieved on eight out of thirteen of the newly planted sites.

Two more observations were also made which may be relevant to the plot growth recorded. On each site the trees planted directly adjacent to windrows were distinctly larger and had suffered lower mortality. It appeared possible that the release of nutrients, or shelter effect, from the windrows had greatly increased the diameter and height of these trees as can be seen in Figure 6 (left). This was a feature seen on all of the young plantations (windrows were not observed on the older plantations). Insect damage was also observed, caused by the beetle *Paropsisterna selmani* (see Figure 6, right). This damage was widespread and was evident on all the young *E. nitens* plantations, but was not observed on the older plantations. Only a visual record of presence was made, but the damage appeared to affect all the trees inspected on the sites. According to Bars (2013), such damage could cause up to a 50% reduction in volume production.

The productivity on the sites ranged from 0.4 – 12.6 odt ha^{-1} yr^{-1}, depending on stand development. Unfortunately, there are no plantations in Ireland between 8 and 21 years old, and so an understanding of the productivities for the recommended rotation length of 10 – 15 years has not been estimated. Thompson et. al. (2012) observed productivities of 11 – 14 odt ha^{-1} yr^{-1} in Irish plantations of 16 to 28 years of age, which are similar to the older plantations observed here. Kerr (2011), reported that, on a short rotation in the UK, *E. glaucescens* can produce 2.5 – 7.6 odt ha^{-1} yr^{-1}, and *E. gunnii* can produce 1.5 – 8.2 odt ha^{-1} yr^{-1} for rotations of less than 10 years. The majority of the younger plantations here in this study were achieving within this range, with the exception of site 4, which has suffered high mortality, and 14 and

Figure 6: *Left: A seven-year-old* Eucalyptus nitens *plantation in Kilmacthomas, Co. Waterford (sample site no. 6). Note the change in size of trees with proximity to the windrow. Right: Leaf damage caused by* Paropsisterna selmani *in Kilworth, Co. Cork (sample site no. 1).*

15 which had only 5 growing seasons. This indicates that the eucalyptus resource in Ireland is performing similarly to the UK, where it has been evaluated by Kerr (2011) that eucalypts have (along with Rauli) the highest potential productivity of any SRF species they reviewed, including Italian alder, red alder, hybrid aspen, sycamore, silver birch, ash, and sweet chestnut. This suggests that the plantations in Ireland are performing well, and may when harvested, be a valuable resource in terms of biomass, but also for the quantification of SRF potential in Ireland.

There may be concerns with how fit for use as a feedstock into biomass boilers some of the eucalyptus partitions are, due to the chemical makeup of the wood and residues. The high chlorine levels of all partitions compared to the EN typical values suggests that there may be issues for some boilers in burning eucalyptus because of the corrosive potential of chlorine. For example, Bord na Móna Edenderry co-fires biomass with peat and has a fuel specification limiting maximum chlorine content to less than 0.1%, expressed on a dry matter basis (O'Halloran 2013). This would mean that eucalyptus residues would not be suitable for co-firing in such a power plant

A further aspect of note, with regard to the fuel specification, was the ash melting behaviour. Ash deformation point was observed as being above 1,500 ^{o}C for all partitions except for the wood and the live branches partitions. Interestingly, the results show that the wood partition material has potential to produce severe slagging with a deformation temperature of below 850 ^{o}C, whereas the stem partition, which is wood *and* bark, had a much higher deformation point, above 1,500 ^{o}C, and a weak potential for slagging. Bord na Móna Edenderry specifies fuel intakes with a minimum ash melting point of greater than 1,000 ^{o}C. Therefore, due to the chlorine content and ash melting behaviour of the samples tested, the only partition suitable for co-firing in the Edenderry power plant would be the stem partition. However, this would not be the case for all boilers, and some are chlorine resistant or operate at lower temperatures which allow for higher chlorine levels. Also, as can be seen from Figure 6, as the stands increase in height, the proportion of the residue to total biomass reduces. In the older plantations, this has been estimated as being 7 – 9%, whereas, as expected, in the 7-year-old plantations, it is estimated as being in the region of 40 – 80%. Therefore, the implication of the chlorine content of the genus will be less as the stands age.

Conclusions

It was observed that the potential for biomass yields in Ireland will be in the region of 6.4 odt ha^{-1} yr^{-1} at age 7, rising to 12.6 odt ha^{-1} yr^{-1} at age 23. Comparing this to literature from the UK, it can be stated that the plantations in Ireland are performing well.

The mortality rates were high. The average mortality rate was 28%, and ranged from 11% to 62%. There was only one standing dead tree identified in the 5- to 7-year-old plantations, indicating that mortality had occurred very early in the rotation, possibly due to the exceptionally low temperature events of 2010.

The analysis of sample tree partitions identified that the bark, branches, tops, and foliage may be unsuitable for combustion in certain boilers due to the high levels of chlorine and potential for slagging. This has implications for markets for eucalyptus biomass, particularly as the branches, tops, and foliage are the partitions which make up logging residues, a commonly used wood fuel product. If there is a significant amount of this material being mobilised in the future, then boilers should be configured appropriately to accept it.

A biomass expansion factor equation was developed for the analysis within this paper. This model should be transferable for other stakeholders who wish to make biomass estimates of eucalyptus plantations in the future.

The lack of data from plantations aged 8 – 21 years has restricted the development of productivity estimates for the likely range of harvest years. The biomass expansion factor has been formulated to give first estimates of biomass for eucalyptus in Ireland, but more data should be added as it becomes available.

References

Barrs, J.R., Hayden, D. and Fanning, P. 2013. Classical biological control of eucalyptus pests. Available at http://www.impactproject.eu/ [Accessed April 2017].

Christersson, L. and Verma, K. 2006. Short-rotation forestry – a complement to "conventional" forestry. *Unasylva* 57 (223): 24-39.

Coates, E., Cronin, B. and Kent, T. 2016. A comparison of biomass production and machine system productivity using three harvesting methods in a conifer first thinning. *Irish Forestry* 73: 122-140.

Coates, E., Kent, T., Horgan, B. and Mockler, N. 2014. Residue bundling – a case study in Ireland. *Irish Forestry* 71: 76–91.

DAFM. 2014. *Forestry Programme 2014 –2020: Ireland*. Dublin, Ireland: Forest Service, Department of Agriculture Food and the Marine.

DIEF – Min. Agricultura. 2000. *Informação estatística 3rd revisão. Inventário Florestal*. Lisbon. Cited in Spinelli, R., Ward, S.M. and Owende, P.M. A harvest and transport cost model for Eucalyptus spp. fast-growing short rotation plantations. *Biomass and Bioenergy* 33 (9): 1265-1270.

Ray, D., Xenakis G., Tene, A. and Black, K. 2009. Developing a site classification system to assess the impact of climate change on species selection in Ireland. *Irish Forestry* 66: 101-122.

EN 14774-3. 2009. *Solid biofuels* - Determination of moisture content. Oven dry method – Part 3: Moisture in general analysis sample.

EN 14775. 2009. *Solid biofuels* - Determination of ash content.

EN 14918. 2009. *Solid biofuels* - Determination of calorific value.

EN 14961-1. 2010. *Fuel specifications and classes* – Part 1: General requirement.

European Directive 2009/28/EC of the European Parliament and of the council of 23rd April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. *Official Journal of the European Union* 140: 16–61.

Geographic Resource Solutions. 2016. *The GRS Densiometer.* Available at http://www.grsgis.com [Accessed March 2017].

ISO 14778. 2011. *Solid Biofuels* – Sampling.

Johansson, T. and Karačić, A. 2011. Increment and biomass in hybrid poplar and some practical implications. *Biomass and Bioenergy* 35: 1925-1934.

Leslie, A.D., Mencuccini M. and Perks, M. The potential for Eucalyptus as a wood fuel in the UK. *Applied Energy* 89: 176-182.

Levy, P.E., Hale, S.E. and Nicoll, B.C. 2004. Biomass expansion factors and root: shoot ratios for coniferous tree species in Great Britain. *Forestry* 77: 421-430.

Matthews, R.W. and Mackie, E.D. 2006. *Forest Mensuration: A Handbook for Practitioners*. Forestry Commission. Edinburgh.

Kerr, G. 2011. A review of the growth, yield and biomass distribution of species planted in the English network trials of Short Rotation Forestry. In *Short rotation forestry: review of growth and environmental impacts. Forest Research Monograph 2.* McKay, H. (Ed.), Forest Research. Surrey. pp 135-160.

O'Halloran, J. 2013. *Biomass to Megawatts*. Presented at the ITGA conference on the 10th of May, Stradbally, Co. Laois. Available online at http://www.itga.ie/itgaconference.asp [Accessed April 2017].

SEAI. 2004. *Co-Firing with Biomass*. Glasnevin, Dublin.

Serup, H. and Koffman, P.D. 2005. *Wood for Energy Production: Technology, Environment, Economy*. Danish Energy Authority and COFORD.

Stam, A.F., Livingston, W.R., Cremers, M.F.G. and Brem, G. 2009. *Review of models and tools for slagging and fouling predictions for biomass co-combustion*. IEA

Task 32 Biomass Combustion and Co-firing.

Thompson, D., Hutchinson, K. and Berkery, B. 2012. Recent results of growing *Eucalyptus* in Ireland. *Irish Forestry* 69: 167-183.

Thygesen, L.G. 1994. Determination of dry matter content and basic density of Norway spruce by near infrared reflectance and transmittance spectroscopy. *Journal of Near Infrared Spectroscopy* 2**:** 127-135.

Tobin, B. and Nieuwenhuis, M. 2007 Biomass expansion factors for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Ireland. *European Journal of Forest Research* 126: 189-196.

A comparison of market opportunities for short rotation forestry in Ireland and Oregon

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Abstract

Short Rotation Forestry (SRF) is the practice of cultivating fast-growing tree species mainly for the production of biomass. In Ireland, SRF rotation lengths are less than 20 years. SRF forest cover is expected to increase in response to the increasing demand for fibre products and renewable energy targets set by the European Union. Although Irish policy supports the establishment of SRF, prior research identified Irish forest industry concerns over the market opportunities for SRF, which may limit its establishment. A SRF market was successfully established in Oregon, U.S., mainly based on hybrid poplar (*Populus* spp.). A survey was carried out there and its results were supplemented by US-based literature. The objective was to benchmark conditions that facilitated market development in Oregon with current conditions in Ireland, to identify and describe gaps and opportunities that hat could be applicable to growers and potential users of SRF in Ireland.

The key success factors in growing and marketing SRF in Oregon were large-scale plantations, local supply chains, consistency of supply, FSC certification and the targeting of high-value products. Small-scale plantations and low-value product systems were unsuccessful in Oregon. However, liquid biofuels and payment for ecosystem services are new opportunities currently in development. These options could also be applied in Ireland to motivate SRF development and improve the sustainability of these plantations.

Keywords: *Hybrid poplar,* Populus*, pulp, wood energy, wood market survey.*

Introduction

Historical development of hybrid poplar in Oregon

In 1893 the first poplar plantation was established in the Pacific Northwest (PNW) (Bourque et al. 2014). The potential of combining western black cottonwood (*Populus trichocarpa* Torrey and A. Gray), a native poplar in the PNW, and eastern cottonwood (*Populus deltoides* W. Bartram ex Marshall) was realised by tree breeders in this region in the early 1970s (Carlson and Berger 1998). Located in the PNW, where many Irish forest species originated, Oregon State invested significantly in research and commercialisation, so that new markets were developed in hybrid poplar production

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and processing. Hybrid poplar was first used as a fuel (Hansen et al. 1983) and then planted to meet the forecasted shortage in pulp for the paper industry (Figure 1). Initial stocking of 1,500 trees ha^{-1} could produce 62 to 100 dry tonnes (dt) ha^{-1} of clean chips and additionally from 22 to 33 dt ha^{-1} of residue biomass on a 7- to 10-year rotation (Stanton et al. 2002).

Farmers established hybrid poplar plantations, motivated by the potential profits indicated by research and supported by the paper mill markets. Although there were no specific grants for afforestation with hybrid poplar, some landowners could avail of cost sharing funds from the Agricultural Stabilization and Conservation Service if rotations were over 10 years (Heilman et al. 1990) in order to enhance the environmental benefits resulting from a longer rotation. Small landowners' plantations ranged from a few hectares up to 100 ha (Figure 2).

Also, in the eighties and nineties, five pulp and paper mills established significant poplar plantations (a minimum of 3,000 ha each) with the aim of supplying material for their own production (Bourque et al. 2014). In 2002 it was estimated that there was over 20,000 ha of hybrid poplar in the PNW (Stanton et al. 2002). However, markets did not develop as the forecasts had predicted. The decline of the paper industry and low pulp prices forced the closure of plants and the sale of plantations resulting in a reorganisation of the ownership structure.

Boardman plantation

An example of the industrial development of hybrid poplar SRF in Oregon is the poplar plantation in the Boardman region of eastern Oregon. Although this is a very dry area, the land has water rights from the Columbia River so the poplar plantation was irrigated. Established in 1992 for the pulp and paper mill, this 7,000 ha plantation and on-site chip mill were acquired in 2007 by GreenWood Resources, a timber investment and asset management company, with the aim of finding new markets

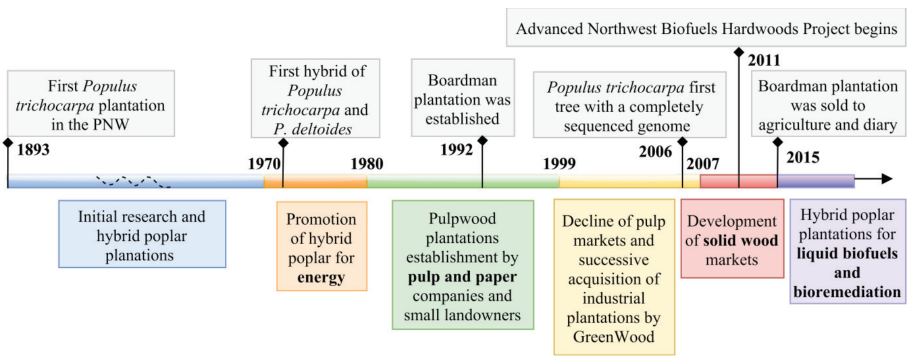

Figure 1: *Timeline describing the use of hybrid poplar in SRF systems in the Pacific Northwest.*

Figure 2: *Whole-tree harvesting of a 12-year-old 60-ha hybrid poplar plantation belonging to a small landowner in the Willamette Valley, Oregon in 2004. (Photography credit Don Wirth.)*

for higher-value products from hybrid poplar (Rinaldi 2015). GreenWood invested in research and innovation on silvicultural practices and clonal material to improve productivity and disease resistance (Stanton 2005, Stanton 2011) and to develop expertise in hybrid poplar management.

In 2008 a sawmill was built in the middle of the plantation (Figure 3), while in 2013 a veneer mill to manufacture plywood was established next to the sawmill. Products such as wine boxes, ceilings, pencils, and interior frames for furniture were made from boards produced from the sawlogs. The plywood was used mainly to produce cabinets. The residues were used for pulp for the paper industry and for energy. The poplar plantation increased to over 10,000 ha through subsequent acquisitions (Rinaldi 2015). However, in 2015 the plantation was sold and is now in the process of being converted to agriculture. GreenWood still owns another 2,000 ha of poplar in west Oregon that is mainly used for pulp, paper and veneer production.

New opportunities for SRF in Oregon

Currently the $40 million Advanced Hardwoods Biofuels (AHB) project, funded by the U.S. Department of Agriculture, is investigating how to develop a renewable transportation

Figure 3: *Boardman poplar plantation and sawmill. Oregon, August 2016.*

fuels industry by growing and converting hybrid poplars into liquid biofuels. Poplar for biofuel use is grown in a coppice system on a three-year rotation (Figure 4).

Poplar is a suitable feedstock for energy generation due to: 1) its ability to coppice and accumulate biomass quickly, 2) its suitability to grow strongly on marginal lands and 3) its wood composition which is adequate for the conversion process (Budsberg et al. 2016). However, low fossil fuel prices and lack of economic incentives for renewables make the viability of biofuels a challenge. Furthermore, poplar plantations will need to be of sufficient scale to fuel biorefineries all year round and be located near the refineries to reduce transport costs. The production of plant-derived biochemicals (such as paints, plastics, packaging, and cosmetics) is being investigated to improve financial viability (Crawford et al. 2016).

Another option for poplar being explored in Oregon is the payment to forest owners for the provision of ecosystem services such as carbon storage or remediation of pollution (Figure 5). There is increasing interest in such payments and approximately 5,000 ha of poplar plantations are grown primarily for environmental services in the PNW, although at this time only 2% of municipalities have applied this system (Gustafson 2016). In addition, hybrid poplar wood has been tested for engineered wood product manufacture such as Cross Laminated Timber (CLT). While initial tests indicated that it met strength requirements, it did not pass stiffness specifications. Mixing poplar wood with higher density species had the potential to improve stiffness results (Kramer et al. 2013).

An exploration of the market opportunities for SRF in Ireland was carried out

Figure 4: *A three-year-old second rotation hybrid poplar coppice plantation, ready for harvesting, chipping and converting in liquid biofuel for energy generation in Jefferson, Oregon. October 2016.*

by de Miguel et al. (2016). This study aims to benchmark the conditions in Ireland identified by that publication with those that facilitated market development in Oregon. Benchmarking design and analysis involves identification of good practice cases, rigorous study of one's own practices (e.g. using site visits and interviews), and development of recommendations for potential implementation (Garvin 1993, Hothorn et al. 2005). This methodology has been applied in various forestry sectors, such as for the development of clone propagation methods (Pilbeam 2004), forest certification (KCBS 2006), forest biodiversity (European Commission 2011) and the wood products industry (Mitchell 2012).

The main objectives of this study were 1) to identify the conditions in Oregon that facilitated the successful implementation of SRF and 2) to identify gaps between the circumstances in Ireland and Oregon that may deter development of SRF in Ireland, and to suggest ways to address such issues. Previous work revealed the Irish wood energy sector and pallet industry may be favourable towards using SRF, but other

Figure 5: *Hybrid poplar at the Biocycle Tree Farm in Eugene, Oregon. This plantation recycled wastewater treatment by-product from two cities, Eugene and Springfield. Trees were harvested every 10 years to generate revenue to balance against operating expenses. In the background an eight-year-old stand can be seen. In the foreground a stand replanted a few months before the photograph was taken in October 2016. (Photo credit Rick Zenn.)*

market sectors were negative about SRF, citing doubts about wood properties and lack of sufficient supply of raw material (de Miguel et al. 2016). That survey identified the need to provide the industry with the following information: wood properties of SRF-grown species; suitability as a wood fuel; the current afforestation grant supports for SRF. This survey of the Oregon SRF sector aimed to reveal perceptions on the suitability of SRF material for different products in Oregon and to discover the drivers that initially gave industry confidence to use SRF systems. The survey aimed to investigate the availability and importance of information on the characteristics of the raw material. The scale of annual raw material production required in Oregon, and balancing of supply and demand, will be described, as this was considered an important prerequisite by the Irish processing sector in potentially using SRF material.

Materials and methods

Benchmarking analysis was the process used to understand and learn from good practice case studies of SRF hybrid poplar production in Oregon. A survey of the hybrid poplar industry chain in Oregon was completed by semi-structured interviews of industry stakeholders, following the same methodology described in de Miguel et al. (2016). Fourteen interviews were carried out between August and October 2016 in Oregon. The sample was chosen mainly by the snowball technique, whereby new survey participants were nominated by some interviewees. As the target was to compare the survey results to those previously described for current Irish conditions, purposive sampling was followed, so markets not currently in Ireland, such as pulp and paper mills, were ignored. Seven users of SRF-grown material in Oregon, made up of primary and secondary wood processors, were identified and interviewed. To develop a comprehensive understanding of the case study, it was necessary to capture perspectives of people from different points of view, so poplar growers were also interviewed. These other interviewees were two small forest landowners, two university extension officers advising hybrid poplar growers, and three managers of larger scale plantations (Table 1 and Figure 6).

The triangulation method, meaning validation of the survey responses from other sources, was used to verify the data collected in the interviews (Patton 1999, Carter et al. 2014). Three researchers involved in hybrid poplar development in Oregon confirmed the information supplied by the interviewees, filled in gaps and provided additional background information. Also, relevant literature including harvest reports, market survey reports, marketing materials, and sawmill technology information, were reviewed and included in the analysis. Consistency in general patterns was expected. However, when there were contrasting findings from different sources, reasonable explanations were given and in this way they contributed to the overall credibility of the results (Patton 1999). Another difference to the study in Ireland was that survey results focused on qualitative analysis only as the objective was to identify conditions that facilitated SRF development. Questions focused on perceptions of using hybrid poplar in SRF, specifications of raw material, supply-demand balance, and source of the raw material. Interviews were transcribed and the software N-Vivo (QRS International Pty Ltd., Australia) a qualitative data management tool, was used to analyse them.

Results from the Oregon study were compared to results from a similar survey carried out previously in Ireland (de Miguel et al. 2016). This comparison was carried out using the benchmarking potential analysis methodology (Garvin 1993) that involves the identification of good practice cases and the development of recommendations for potential implementation. Oregon good practices and strategies for success were identified and recommendations for gaps and weaknesses recognised in the Irish survey were developed.

Results

The number of interviews was smaller than for the survey in Ireland, but more homogeneous since all interviewees were directly involved in the SRF hybrid poplar sector.

Table 1: *Numbers of survey participants and their categories.*

Target group	Sector	Number of participants	Interview type
SRF users	Primary wood processors (sawmill and chips mills, veneer mill and biomass power plant)	3	Face-to-face
	Secondary wood processors (sawlog users, plywood and briquettes)	4	Face-to-face (2) Phone (1) Email (1)
SRF growers	Managers	3	Face-to-face
	Small landowners	2	Face-to-face
	Extension agents	2	Face-to-face

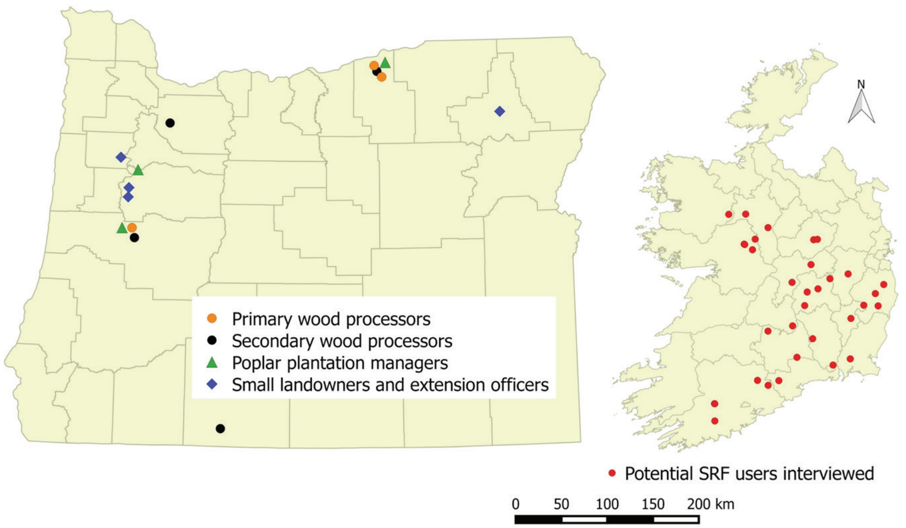

Figure 6: *A scaled comparison between Oregon (left) and Ireland (right) showing the locations of participants in the survey. Oregon has a land area of 25.5 million ha and 48% forest cover whereas the Republic of Ireland covers an area of 7 million ha and forest cover of 11%.*

Perceptions of Short Rotation Forestry in Oregon

Although nowadays hybrid poplar and its wood properties are well-known in Oregon, there was an initial lack of knowledge within the industry prior to using it. Information needs were satisfied by university research and extension, and companies carrying out their own research and testing. Wood processors confirmed that this information was an important factor in enhancing confidence to use SRF hybrid poplar: "We knew it was difficult to machine but I guess it was [required] a lot of testing and trial and error"; "...marketing materials that talked about the properties of the wood, so that you could compare to other species; ultimately you just have to try it. You just have to run it and see how it does."

Specifically, it was important to compare poplar wood property values with those of the most common species used at the time and to define expected poplar grades.

> ...this [wood properties information] was very important early on when we were introducing the species to the customers; they said what are they like? What are the properties? Compared to pine, compared to alder? So this was really useful early on.

In addition to the lack of knowledge on wood properties, hybrid poplar suffered from a bad reputation in the forest industry, which was another barrier to its introduction. Industry had preference for other species or specifically preferred not to use poplar. Initially, the majority of the sawn board production was exported to Asia but subsequently it was accepted in the PNW and markets were developed locally. Hybrid poplar wood became a competitive commercial species in the PNW and there was potential to increase plantation area. One of the marketing strategies was to rebrand poplar wood as Pacific Albus to eliminate negative perceptions about poplar and cottonwood (Figure 7).

> Pacific Albus grows only in that plantation in Boardman....since the plantation closed, we are looking at other sources of poplar in other parts of the world...but it would not be Pacific Albus, it would be some other types of poplar.

Figure 7: *SRF hybrid poplar is promoted as Pacific Albus wood, here showing different board grades.*

Regarding willingness to use SRF, all the companies interviewed reported a willingness to continue using poplar. Users of poplar from the plantation in Boardman were very disappointed that their log supply would cease as they saw many advantages on using hybrid poplar: “there were many, many positives for us; it is very disappointing that it is going away...I was sorry to see it go”; “We have loved Pacific Albus for our market. We will really miss it!” Managers at Greenwood confirmed the strong demand from processors, and expressed disappointment that the plantation was being sold for conversion to agriculture.

However, small forest landowners were not willing to establish hybrid poplar. Although hybrid poplar for liquid biofuels is currently being promoted, they had some concerns to establish new poplar plantations due to previous difficulties in marketing poplar to end-users.

> Now cottonwood [hybrid poplar] has come back in the last few years: the excitement has been for biofuels...they have been asking us and they haven't been getting a lot of enthusiasm from us.

Raw material: quantity, suppliers, distance

The majority of the hybrid poplar raw material sold in Oregon came from the Boardman plantation which grew >10,000 ha of SRF. However, a third of the plantation had already been harvested at the end of 2016 and the land was converted to agriculture. The amount of hybrid poplar from this plantation will be significantly lower in the coming years until the SRF plantations have been completely cleared. In future, harvested roundwood will only be used to produce veneer, as the sawmill has already been closed. Although there is an obvious gap in supply, owners of smaller scale plantations think they will still have difficulties in marketing hybrid poplar timber. The reasons provided seem to be the small volumes individual forest owners can produce and the long distance to supply to markets, particularly for low-value products.

> [The veneer mill] was happy. They took the poplar and made some plywood sheets out of it...later on he [the veneer mill] said: you know, we buy so much volume that this is actually more hassle...then I realised we were pretty small fish in a big pond here in terms of wood products.

Companies confirmed they did not like dealing with small landowners as they needed consistency in supply.

> We need a lot of quantity, that’s why we like the Boardman plantation because it was a large plantation with specific quality. We are not interested in buying a few poplar here and there,

> because the quality varies a lot with location; so we try to work with large plantations as they can supply us quite a bit of wood on a regular basis for the long term.

Requirements of raw material

Supply consistency seems to be an essential requirement for SRF users. Boardman material users highlighted the advantages of a secure supply and also the uniformity of the material as it came from the same plantation: "In general for people who want to use poplar they like large plantations because they want the consistency of the supply but also the quality".

Price was another characteristic that made hybrid poplar attractive: "...very economical price-wise...stains well to look like other premium hardwoods, looks like solid maple, but a lot less money."

The particular appearance of hybrid poplar wood, its light colour and weight were also considered advantages for sawn timber products: "The nice thing about hybrid poplar is a very light colour, so if you start with a light colour you can make every colour, if you have alder, walnut, you can't make it lighter"; "One of the nice things of Pacific Albus is the light weight...most of the time what happens is it gets used internally in a product, with the exception of the wine boxes, but our customers like the look."

Among the other advantages of using hybrid poplar from the Boardman plantation was its FSC (Forest Stewardship Council) certification status, a particularly appreciated aspect in the marketplace.

> ...even though it was a lower quality wood, the fact that it was certified helped it to be accepted by some of our customers. We are looking now at some certified woods to replace Pacific Albus because there is a need for it.

Other plantations also confirmed certification was required for them to market SRF poplar for sawn timber or veneer: "If we can grow the stuff and meet their expectations, and we are FSC certified, without that there really doesn't seem to be anything doing..."

On the other hand, there were some challenges regarding wood properties of hybrid poplar, partly because of the change of market, from pulp production to the sawn-board market. For instance, clones with higher yield for pulp production presented problems with straightness for sawn timber or with distortion during the drying process. Industry solved these problems by adapting their production technology and processes to these particular wood characteristics.

> We said ok you got a curvy tree, we solved by using curved log scanning technology...if you trying to follow the log curvature

> you are going to reduce your slope and grain, you are going to have a better quality piece of lumber, better recovery...the long term was to try to grow the tree straight

Secondary producers also found some challenges at first working with poplar wood including: the roughness of the finished products; learning how to stain it; and the type of fasteners to use; but again they adapted to poplar wood properties.

> The biggest problem was the poplar makes a fuzzy, a very rough surface, so it requires different tooling, more steps, sometimes sanding maybe. We had to assume that we were able to make it work, but definitely that was challenging. A bit more difficult to work than other woods.

Hybrid poplar wood fuel was used in biomass power plants and sawmill residues were also used to produce briquettes. Some challenges identified for using hybrid poplar as a wood fuel were moisture content, contamination due to leaf content and inability to meet the prices achieved in other poplar wood markets such as the pulp and paper.

> ...it is worth about twice as much in the form of chips [for pulp and paper] as what we can pay bringing in to burn in our facility. Poplar has a relatively high moisture content and that is a problem when it comes to renewable cogeneration power...if we could get the whole tree yes, but my concern would be that it would be a very expensive fuel for us at that time...if they couldn't sell it to the pulp mills then yeah.

Balance of supply and demand

Regarding raw material for pulp and paper, contrary to the forecasts, production in this sector decreased as demand for paper declined so there was no longer a raw material shortage and pulp prices reduced. In addition, not as many landowners as expected planted hybrid poplar. Those that did had difficulties in selling the timber and in some cases they have not harvested or have harvested at a loss just to convert the land to agriculture.

> What got me into it was we live in a world of poplar here. I just thought there was going to be a shortage of pulp and there is fewer mills than there was...I ended up with those of them that didn't sell so I had 40 acres that I burned.
>
> There is a couple of growers in the region who had some history of it and at some point they said I am getting out and there is a couple that weren't as involved and left it, like the guy who called me the other day: there is a 30 years old stand, giant, I don't know what he is going do with it.

Before the Boardman plantation was sold in 2015, demand for sawn timber and veneer was increasing and expansion of hybrid poplar growing was required as some businesses were planning to expand: "I have felt that demand has grown beyond supply, as it relates to the Superior Grade [clearest grade]"; "I would say it was pretty well balanced, but there were times, some times when we wanted some of the higher grade material and we couldn't get it."

After the large Boardman plantation was sold there was a gap in supply and users have concerns about how to replace the poplar wood that has been the mainstay of some of their products and that they were basing expansion around. They had to look for other species to replace poplar as there was not enough poplar in Oregon to replace the amount that was produced by Boardman: "We are looking into different species: finding poplar is very difficult"; "Yes, a big concern. We need to find a replacement for Pacific Albus now. We are not sure what we will do."

Potential markets

Liquid biofuels, payment for ecosystem services such as carbon and bio-remediation, and engineered products such as CLT are options currently being explored for poplar plantations. However, managers and landowners think these potential markets will still take some years to develop, so they need to find some replacement markets until then: "Being optimistic but also being realistic, probably 20 years down the road the stuff becomes biofuel feedstock. We need to create some markets in between and build up the amount of poplar that is being grown."

The variability in the price of crude oil plays an important role in the viability of biofuel refinement from biomass.

> Back in 2011 oil was up over $100 a barrel and at that point making fuels from feedstock was pretty economically viable, but since then the price of oil has dropped down to about $40 a barrel, which makes it very difficult to compete with making fuels and chemicals from biomass sources.

Benchmarking potential analysis

Results described above were compared to the results from the previous survey in Ireland. The parameters evaluated were land use classification of SRF, availability of grants, availability of information e.g. wood properties, initial level of knowledge about SRF, reputation, willingness to use, past experiences, quantity of raw material, industry preferred source of raw material, distance of supply, requirements of raw material and potential markets identified (Table 2). The same requirements that had been recognised in the survey in Ireland (e.g. supply consistency) were then evaluated in relation to poplar in Oregon.

Table 2: *Analysis of benchmarking potential for use of SRF in Ireland, in comparison to Oregon where SRF plantations and markets were established and well developed.*

Parameters	Ireland	Oregon	Key factors for development of SRF in Oregon
SRF land use	Forestry	Agriculture (maximum of 12 years rotation)	Although no funding available, reduced risk as it was possible to revert to agriculture
SRF grants	Forestry for fibre afforestation grants	No afforestation grants specifically for SRF	
Information availability	70% identified gaps and needs	No information initially, now available	University and/or industry research and knowledge transfer through extension foresters
Initial knowledge	76% not familiar with SRF	Not familiar initially, now familiar	Dissemination by sawmill, university and extension
Reputation	Poor	Initially poor, now good	Marketing: renamed as Pacific Albus Proven processing experience and market
Willingness to use	30% favourable	100% of industry favourable, not initially	Research, own testing, marketing, repeat customers
Past negative experiences	*Miscanthus* and SRC willow	Hybrid poplar for pulp and paper	Marketing, testing and extension dissemination
Quantity of raw material	Targeted 3,300 ha from 2014 to 2020 (DAFM, 2014)	Industrial plantations (over 12,000 ha in 2015) plus small plantations	Large scale, 10,000 ha plantation
Industry preferred source of raw material	Not from small landowners	Not from small landowners	Large scale industrial plantation
Distance of supply	Anywhere in Ireland, but no more than 50 km for wood fuel	Mills on site, secondary wood processors first in Asia, then in PNW	Locally sourced log supply
Requirements of raw material identified in the Irish survey and evaluated by wood processors in Oregon	Supply consistency	✓ Advantage	Large plantation: volume and uniform quality
	Cheap price	✓Advantage	Low cost and fast growing
	Appearance	✓Advantage: light weight and colour	Find niche markets
	Certification	✓Advantage	Allowed entry to new markets or survival in traditional markets
	Straightness	× Challenge	Investment in suitable cutting technology and straighter clones
	Low moisture content	× Challenge	Investment in moisture testing and drying technology
Potential markets	Solid biofuels and pallets	1980-1999: pulp and paper 2000-2015: solid wood products Future: Liquid biofuels and ecosystem services	Flexibility, adaptability and research (different clones better for specific products)

Discussion

Differences between Oregon and Ireland in policy issues such as land use classification and the process of change of use category were identified. While 12-year rotation SRF is considered agricultural land in Oregon, it is considered forestry in Ireland and should remain in forestry as specified in the Forestry Act (2014). Most of the small landowners who invested in SRF in Oregon went back to agriculture due to their inability to market the SRF produce. There were no specific grants for SRF in Oregon, unlike SRF afforestation incentives in Ireland. However, in Oregon landowners had the flexibility to try SRF and return land to agriculture after one rotation. The permanency of the requirement of staying in forestry may be one factor that will limit the establishment of SRF in Ireland.

In line with the findings of the Irish survey (de Miguel et al. 2016), growers and end-users in Oregon initially required information on SRF, particularly on wood and fuel properties. This appears to be an important gap to fill to start market development. Furthermore, product testing by researchers and industry was also needed in Oregon.

Negative perceptions by industry towards hybrid poplar wood were a barrier to the introduction of SRF for sawn products in Oregon and biases towards using SRF were also identified in Ireland. In Oregon this bias was overcome by the marketing strategy of branding the species with the name Pacific Albus, together with dissemination of wood property information and prepared samples. In Ireland, wood property information and product test samples, at least, are needed in order to counter industry preconceptions.

Skepticism of SRF viability was expressed by small-scale poplar growers. The promotion of hybrid poplar to fill the forecasted shortage in the pulp market, which did not happen, dampened Oregon growers' interest in the potential new market for poplar for liquid biofuels. Oil price fluctuations also contributed to increase this reluctance. A similar situation was found in Ireland, where doubts were raised about the viability of SRF due to unsuccessful market development for other energy crops, e.g. elephant grass (*Miscanthus* spp.), previously extensively promoted. A proven and consolidated market could be needed to get these growers investing in SRF.

Development of SRF in Oregon was based on a large scale industrial plantation of 10,000 ha. This was a successful model that only ended due to the plantation land being sold for agricultural development (Stanton 2016). Boswell et al. (2008) estimated that approximately 7,000 ha of hybrid poplar would be needed to develop a sustainable model, considering this the minimum volume to get cost effective production as well as to attract the added value processing infrastructure. However, 3,300 ha is targeted to be afforested with SRF in the period 2014-2020 under the Irish forestry programme (DAFM 2014). Similarities in the volume of raw material supply required by the Oregonian and Irish wood processing industries and reluctance to deal with many small suppliers (de Miguel et al. 2016) indicate that large-scale plantations will be needed to develop markets in Ireland. Production scale may be achieved in two ways: 1) the industrial approach followed in Oregon by GreenWood; or 2) by forming effective producer groups of small forest owners with clustered plantations. However, this latter approach was not very successful in Oregon (Stanton et al. 2002), as smaller forest owners could neither guarantee the consistency of supply or quality required by users. Distance from plantation to market was also a crucial issue, particularly when low-value products were transported. Both in-situ mills and high-value products were needed for a successful supply chain in Oregon. As low-value products are the main goal for SRF in Ireland, an in-situ end-use or locally available supply would seem to be required.

Similarities were found between Oregonian and Irish companies' preferences for raw material requirements. In addition to security of supply, raw material price and appearance were identified as important to end-users in both surveys. Certification was also a requirement highlighted by the Oregonian sawn-timber industry and is increasingly required in Ireland. The requirement for straight logs for certain products was identified in Ireland. Research, testing and technology adaptability helped to solve these difficulties in Oregon and a similar approach could be adopted in Ireland.

Mixed views regarding the supply-demand balance were found in both cases. While sawmills found difficulties in sourcing their raw material in Oregon and Ireland, woodfuel producers in Ireland and small growers in Oregon found there was more raw material available than demand for it.

Policy requirements in response to environmental issues, e.g. the use of renewable energy, remediation of pollution and construction with renewable materials, were the drivers for development of new markets for hybrid poplar in Oregon and may be options to explore in Ireland. Meeting renewable energy targets provides a suitable reason for the State to heavily incentivise investors or growers to meet these targets. That would provide the impetus to develop a market, from which point ordinary market forces would ensure its success or failure. The wood energy sector was the most favourable to use SRF in Ireland, so developing biorefining to produce liquid biofuels could be an option to explore if sufficient scale of feedstock production was feasible and fossil fuel prices increased.

Conclusion

Oregon developed a model of growing and marketing SRF hybrid poplar based on large-scale industrial plantations, in-situ processing mills, certification and high value product market development. However, small plantations and lower value products were not successful. Furthermore, there is now a shortage of hybrid poplar wood supply in Oregon that will increase to about 400,000 m^3 yr^{-1} when the Boardman plantation is completely converted to agriculture. However, such a shortfall in supply would not guarantee that an individual grower could secure a financially viable place in this market due to requirements for production scale and log quality that the processing sector demanded. Learning from the Oregon experience, Ireland must consider the importance of scale and management of quality, so the development of co-operative producer groups would be essential. Moreover, industry should provide clear guidance on pricing related to size and quality specifications.

Another lesson from the approach to SRF in Oregon was the need for flexibility to adapt to changing circumstances. Although the wood energy sector was identified as a potential market for SRF in Ireland and a future shortage of woodfuel is expected, market demands can change by the time plantations reach rotation age, as happened in the pulp sector in Oregon. Flexibility of management is an advantage of the SRF model proposed in Ireland, based on single stem trees and 10- to 20-year rotations, and with the possibility of conversion to conventional forestry systems. However, if other markets need to be targeted in the future, then different species, stocking and silvicultural practices may be required.

Although flexibility can help market development, there is a risk of a commercial supply chain ending even when successful markets have been developed. For instance, land competition from other higher value uses can hinder the development of SRF, e.g. another agricultural crop in Oregon or another Grant Premium Category of the forestry programme in Ireland. Research and dissemination actions together with marketing strategies were essential to the development of SRF in Oregon for both growers and markets; the same approach will most likely be needed in Ireland.

Although development of high value products was essential in Oregon, wood energy was the sector most favourable towards using SRF in Ireland. The Oregon experience highlights a series of possible challenges for economically sustainable energy feedstock supply:

- minimum production scale;
- locally available consistent supply of SRF for energy;
- requirement for as short a supply time (rotation length) as possible;
- consideration of coppice techniques to reduce establishment costs;
- need for higher value products to increase financial revenue for the grower.

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References

Boswell, C., Eaton, J. and Bourque, A. 2008. *Lake County Hybrid Poplar Study and Carbon Sequestration Opportunities.* GreenWood Resources Inc.

Bourque, A., Stanton, B., Shuren, R. and Turland, J. 2014. *Feedstock Analysis for Poplar Plantations within the Western Montana Corridor*. Northwest Advanced Renewables Alliance.

Budsberg, E., Crawford, J.T., Morgan, H., Chin, W.S., Bura, R. and Gustafson, R. 2016. Hydrocarbon bio-jet fuel from bioconversion of poplar biomass: life cycle assessment. *Biotechnology for Biofuels* 9 (1): 170.

Carlson, M. and Berger, V. 1998. *Solid Wood Product Opportunities from Short Rotation Hybrid Poplar Trees*. Kalamalka Forestry Centre. Vernon, B.C.

Carter, N., Bryant-Lukosius, D., DiCenso, A., Blythe, J. and Neville, A.J. 2014. The use of triangulation in qualitative research. *Oncology Nursing Forum* 41: 545-547.

Crawford, J.T., Shan, C.W., Budsberg, E., Morgan, H., Bura, R. and Gustafson, R. 2016. Hydrocarbon bio-jet fuel from bioconversion of poplar biomass: techno-economic assessment. *Biotechnology for Biofuels* 9 (1): 141.

DAFM. 2014. *Forestry Programme 2014 –2020: Ireland. Forest Service*, Department of Agriculture Food and the Marine. Dublin, Ireland.

de Miguel, A., Sottocornola, M., Cronin, B. and Kent, T. 2016. Exploring market opportunities for Short Rotation Forestry in the current Irish wood processing and solid biofuel sectors. *Irish Forestry* 73: 141-160.

European Commission. 2011. *Forestry: Towards Benchmark Methodology for Biodiversity*. The EU Business and Biodiversity Platform.

Government of Ireland. 2014. Forestry Act 2014. Number 31 of 2014. Ireland. Available at: http://www.irishstatutebook.ie/eli/2014/act/31/enacted/en/print.html [Retrieved November 2017].

Garvin, D.A. 1993. Building a learning organization. *Harvard business Review* 71 (4): 78-91.

Gustafson, R. 2016. Advanced hardwood biofuels northwest: five-year update. Available at http://hardwoodbiofuels.org/ahb-five-year-update/ [Retrieved April 2017].

Hansen, E., Moore, L., Netzer, D., Ostry, M., Phipps, H. and Zavitkovski, J. 1983. *Establishing Intensively Cultured Hybrid Poplar Plantations for Fuel and Fiber.* Department of Agriculture, St. Paul, MN (USA).

Heilman, P.E., Hanley, D.P. and Carkner, R.W. 1990. *High Yield Hybrid Poplar Plantations in the Pacific Northwest.* Washington State University Extension, Pullman, p.p. 32.

Hothorn, T., Leisch, F., Zeileis, A. and Hornik, K. 2005. The design and analysis of benchmark experiments. *Journal of Computational and Graphical Statistics* 14 (3): 675-699.

KCBS. 2006. *Forest Certification Benchmarking Assessment.* Kosovo Cluster and Business Support project of Chemonics International Inc. and the United States Agency for International Development.

Kramer, A., Barbosa, A.R. and Sinha, A. 2013. Viability of hybrid poplar in ANSI approved cross-laminated timber applications. *Journal of Materials in Civil Engineering* 26 (7): 06014009.

Mitchell, S. 2012. *Demonstrating Legal Wood Products: Industry Benchmarking: Part I.* Forest and Wood Products Australia: 54.

Patton, M.Q. 1999. Enhancing the quality and credibility of qualitative analysis. *Health Services Research* 34 (5 Pt 2): 1189-1208.

Pilbeam, D. 2004. Benchmarking clonal forestry for blue gum industry adoption. *Australian Forest Grower* 27 (1): 12.

Rinaldi, M. 2015. *Growing Poplar for Growing Markets: A Study of Sawmill Production and Market Dynamics.* Master of Environmental Management. Duke University. Durham.

Stanton, B., Eaton, J., Johnson, J., Rice, D., Schuette, B. and Moser, B. 2002. Hybrid poplar in the Pacific Northwest: The effects of market-driven management. *Journal of Forestry* 100 (4): 28-33.

Stanton, B.J. 2005. The effect of reciprocal hybridisation on reproduction of the intersectional cross, *Populus* × *generosa*. *Forest Genetics* 12 (2): 131.

Stanton, B. 2011 Threshold selection for rust resistance in hybrid poplar: Population response to mass selection. *Silvae Genetica* 60: 266-276.

Stanton, B., Gantz, C., Stonex, R. and Schallich, T. 2016. Market opportunities for hybrid poplar. Available at http://hardwoodbiofuels.org/market-opportunities-for-hybrid-poplar/ [Retrieved April 2017].

The potential impact of differential taxation and social protection measures on farm afforestation decisions

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Abstract

The question of what motivates decisions to change land use or farm management practices has recently received much attention in the context of designing policies to incentivise change. This paper critically analyses aspects of the prevailing incentive policies for farm afforestation, with a view to identifying how different components of income influence the uptake of afforestation. Previous analyses have focused on the role of market income and subsidies in farm income. This paper additionally examines the impact of fiscal instruments on disposable income. The analysis finds that from a household welfare perspective, the inclusion of benefits and taxation in calculating relative life-cycle incomes from forestry and agriculture, provides additional information relevant to the farm afforestation decision. From the policy makers perspective, this analysis illustrates the re-distributive nature of the Irish tax/benefits system as benefits can be very significant at the bottom of the income distribution whereas taxation narrows the gap at the top of the distribution. The analysis shows that even if the level of disposable income is higher for agriculture on more intensive farms, the use of a disposable income measure in analysing the returns from farm afforestation, provides valuable insights in relation to how financial policy levers impact on different farm systems with different levels of farming intensity. At the lower end of the distribution, the analysis shows that low-income farms could acually be slightly worse-off as a result of planting. Further research is required to estimate "cut" points at which changes in taxation or benefit thresholds and increased level of uptake of benefits, could bring about a gain from the inclusion of forestry in overall farm income.

Keywords: *Farm afforestation, disposable income, market, subsidy income.*

Introduction

The question of what motivates decisions to change land use or farm management practices is a complex one which has recently received much attention in the context of designing policies to incentivise change. Examples of recent policy objectives include the protection of water quality and biodiversity, while the issue of climate change is particularly topical in relation to the mitigation of agricultural greenhouse gas (GHG) emissions through the introduction of new technologies and changes

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in land use and farmer behaviour (UN 2016). With ambitious targets to increase agricultural production in Ireland (DAFM 2015a), the GHG mitigation potential of afforestation and forest products is an important component of the climate change mitigation tool-box.

However, afforestation targets across Europe are not being met (EC 2013[1]). Despite a number of increases in the level of forest subsidies over the last 20 years, annual afforestation in Ireland is failing to reach government targets. In the context of changing land use from agriculture to forest (afforestation), this paper uses Ireland as a case study to critically analyse aspects of the prevailing policies which attempt to incentivise farm afforestation, with a view to identifying how different financial instruments influence the uptake of afforestation. There is already extensive literature on farm-level modelling which focuses on farm subsidies (see Ahearn et al. 1985, Keeney 2000, Bhaskar and Beghin 2009). Other quantitative studies in the literature focus only on gross income, which is a combination of market income and subsidies. However, net income should also be considered as tax incentives can be quite important in relation to the determination of disposable income in farm-level decision making (Andersen et al. 2002, Hill and Cahill 2007).

In reality, when an incentive is offered, for example as a subsidy for afforestation, the wider household is affected and other income-related instruments may have implications for the farm family. For instance, in Ireland there are means-tested financial instruments for working-age farm families (Farm Assist) and (non-contributory) pensions for retirement-age farmers. In most European countries the family-farm model is the predominant form of ownership, therefore in looking at the overall incentives available to a farm family considering afforestation, the decision is in fact more complex than has been previously considered in the literature, as the fiscal measures (taxation and social welfare benefits) apply differentially to forestry and agriculture.

In this study, these wider agricultural and forestry income sources are incorporated at micro (farm) level, drawing primarily on research in middle income countries (Xu et al. 2012, Zhong et al. 2012, Lewis et al. 1988). The study focusses on the farm afforestation decision and does not consider institutional or non-farmer afforestation. However, as most of the land suitable for afforestation is in agricultural use, the same opportunity costs and constraints in relation to access to land for planting are likely to apply to non-farmers.

As in the case of other small or medium-sized enterprises, modelling farm taxation poses a challenge in relation to the data necessary for the calculation (Buslei et al.

[1] European Commission. 2013. Forest Europe. Ministerial Conferences. Available at https://www.google.ie/search?hl=en&q=European+Commission+2013.+Ministerial+Confererences+www_foresteurope_org+2011&meta=&gws_rd=ssl [Accessed July 2017].

2014). Household surveys typically only incorporate aggregated self-employment income, while farm surveys incorporate detailed farm expenditure but do not include taxation. To understand the impact of tax incentives on farmer behavour, a hypothetical microsimulation model of agricultural and forestry taxation was developed, utilising a framework similar to that used in benchmarking studies such as the International Farm Comparison Network (IFCN) (Hemme et al. 2000).

To date the role of fiscal incentives/disincentives in the farm afforestation decision has not been examined in any great detail. The theoretical framework section examines the elements of disposable income that could have a financial impact on the land-use change from agriculture to forestry. The methodological section develops a microsimulation framework to model the differential tax regimes of agriculture and forestry on stylised, hypothetical farms, while the data section describes the farm and forest datasets and the relevant tax schedules required for the modelling process.

Theoretical framework

A range of studies (McKillop and Kula 1988, duQuesne 1993, Collier et al. 2002, Behan 2002, McCarthy et al. 2003, Breen et al. 2010, Upton et al. 2013, Ryan et al. 2014a) has found that the rate of afforestation in Ireland is sensitive to both agricultural and forest incomes. From an economic perspective, farmers are assumed to be utility-maximisers and while the permanent nature of the afforestation land-use change (and other associated lifestyle or cultural factors) may pose barriers to the uptake of afforestation, previous research has shown that financial drivers are significant in the planting decision (Ryan and O'Donoghue 2016a). In addition, soil type is one of the primary determinants of both agricultural and forest market incomes. In the case of the farm afforestation decision, where planted land is no longer available for agriculture, it is important to take both market and subsidy returns from both land uses into account. However, previous studies consider only gross income from market transactions and/or subsidies. This paper suggests that analysis of total net income, i.e. disposable income (available to farmers at a given point in time), could provide better information to individuals (farmers) considering a land use change from agriculture to forestry. Otherwise it is suggested that comparing agricultural and forest incomes without including such relevant information is akin to "comparing apples and oranges". The range of parameters affecting farm disposable income is shown in Equation 1.

$$Disposable\ income = \big((market\ income + subsidies + benefits) - (taxation + charges)\big) \quad [1]$$

Thus in order to examine the financial implications for a farm owner considering afforestation, the individual components that make up farm disposable income need to be examined in more detail. These include:

- agricultural subsidies and market income;
- forest subsidies and long-term market income;
- taxation and social welfare provisions in relation to both agriculture and forestry.

<u>Agricultural market income and subsidies</u>

In planting some of their land, farmers forego the agricultural income they would have received from that land if it remained in agriculture. In a recent study, Ryan and O'Donoghue (2016b) show that the highest opportunity costs were incurred by farmers using intensive farm systems, with higher gross incomes on good soils (for example dairy and tillage farms). However, farmers engaged in livestock enterprises benefited most from converting land use forestry. The analysis also showed that larger farms were more likely to afforest land. While the dominant enterprise or system on a farm can have a large effect on market income, the primary physical factor that determines the per-ha market income on farms is soil quality, which affects productivity and livestock carrying capacity[2]. Cattle farms were focussed on primarily in this analysis, as based on the work of Ryan and O'Donoghue (op. cit.) they are the most likely to afforest their land. However, the effect of taxation on higher-earning dairy farms was also examined in the context of afforestation.

Soil type affects stocking rate on farms and thus indirectly affects the level of animal-based subsidies. However, since the decoupling of payments from production in 2004, subsidies are now paid on a per-ha basis, regardless of production. Of the limited studies that include agricultural opportunity costs in the calculation of the economic return from planting land, the majority of calculations are undertaken on a per-ha basis (see Herbohn et al. 2009, Bateman et al. 2005), facilitating comparison between agricultural and forest incomes. Agricultural economic studies use different methodologies to calculate farm returns, depending on the objectives. For the analysis in this study both market and subsidy components of farm income needed to be included. As afforestation generally only occurs on up to 10% of farm land area (Ryan 2016), it was assumed that farms only planted a portion of their land and continued in their main farming enterprise. Thus they continue to incur costs such as overheads (e.g. building repayments) which should be taken into account in calculating returns over a long time period.

Family Farm Income (FFI) is the principal measure derived using Teagasc National Farm Survey (NFS) data to reflect farm income. FFI represents the return from farming to the owners from labour, land and capital. It does not include non-agricultural income

[2] Elevation, slope, access and farmer characteristics (ability and education) also impact on output, but were beyond the scope of this study.

but takes subsidies (Less Favoured Areas (LFA) payments and Basic Payment Scheme (BPS[3])) and overhead costs into account. For clarity, this analysis did not include agri-environment payments which are difficult to model as they are based on environmental actions undertaken and therefore include compliance costs.

$$FFI = (gross\ output + subsidies) - (total\ costs) \qquad [2]$$

where total costs include direct costs (DC) and overhead costs (OC).

Forest market income and subsidies

The international literature concerning forest economics focuses largely on deforestation or management decisions in pre-existing forests, but to a much smaller degree on the calculation or forecasting of the economic return from young or unplanted forest. The factors that need to be taken into account in estimating forest market income include soil type (which is a strong determinant of productivity and is often expressed as yield class[4] (YC) in Ireland and the UK), species, costs incurred in establishing and maintaining forests, timber prices and costs associated with thinning and final harvesting. Growth and YCs for different tree species are determined by factors such as genetic material, soil type, elevation, drainage and vegetation. Forest market return is calculated as the timber volume (in cubic metres (m^3) per ha) by timber assortment, multiplied by the timber assortment price (€ m^{-3}). Forest growth and yield models in combination with average timber prices can thus provide aggregate forecasts of timber yield and value by species, spacing and thinning regime.

There are two main subsidies available for forestry. Afforestation grants cover the cost of new forest establishment on previously agricultural land, and annual subsidy (forest premium) payments compensate for agricultural income foregone until forests can provide income in the form of thinnings[5]. Forest market and subsidy returns can be expressed as:

$$I_{for} = S_{for} - (C_{mgt} + C_{mtc}) + (V_{tim} \times P_{tim}) \qquad [3]$$

where I_{for} is forestry income, S_{for} is annual forestry subsidies, C_{mgt} and C_{mtc} are forest management and maintenance costs, V_{tim} is timber volume ($m^3\ ha^{-1}$) and P_{tim} is timber price (€ m^{-3}).

Farm household income

The NFS does not contain data on the level of off-farm income for a farm family but

[3] BPS is payable on eligible agricultural and forest areas and is liable for income tax.

[4] Yield class (YC) is an estimate of the potential productivity of forest sites (maxium mean average annual volume production per ha). Typically, YC of Irish Sitka spruce plantations ranges from 14-24 $m^3\ ha^{-1}\ y^{-1}$.

[5] Harvesting of smaller trees to allow remaining trees to reach larger sizes. The timing of first thinning is determined by productivity, but generally occurs between years 15-20.

houshehold income is an important aspect of this analysis, thus a measure of typical off-farm/part-time income needs to be included in the analysis.

Taxation incentives

Ireland's system of taxation is progressive, and aims to be re-distributive. This means that as an individual's income rises above certain thresholds, the average tax rate increases, so that changes in income taxation generally have a greater impact on those individuals with higher incomes. Thus in theory, when changes are introduced that increase farm income, for example, the relative benefit for wealthier farms is smaller. Conversely, if farm income decreases, taxation should reduce more for less wealthy farms. It is quite important therefore from a social perspective, to understand the distributional impacts of taxation changes.

In general, there are two types of taxes or charges – income taxation and capital charges/taxation. In this paper only income taxation instruments that affect agriculture and forestry were focussed on, namely:

- Income Tax;
- Pay Related Social Insurance (PRSI);
- Universal Social Charge (USC), which is an income levy payable on gross income.

Agricultural income is liable for all of the above taxes. Income tax is payable on net income while PRSI and USC are payable on gross income. In order to model the impact of benefits and charges on disposable income at farm level, a number of transfer instruments were incorporated, including:

- Farm Assist - means-tested benefit;
- State Pensions - non-contributory means-tested old-age pension.

Means testing

Agricultural and forest income sources are treated differently in relation to means-tested Farm Assist (a payment available to low income farmers) and old-age pensions. The Farm Assist means-test takes account of virtually every form of income but assesses it in different ways and disregards various amounts. Until recently, 100% of forest premium income was liable for Farm Assist, however, payments for agri-environment schemes have historically enjoyed disregards of up to 50%[6]. In March 2017, a 30% disregard for income from agricultural husbandry (including forestry) was introduced (DESPa[7]). In relation to eligibility for non-contributory old-age pensions, net income

[6] First €2,540 of Agri-Environment Payments and 50% of the balance is disregarded. DESP (Department of Employment Affairs and Social Protection). See Farm Assist: Part 2 Entitlement (REPS, SACs and GLAS). Available at http://www.welfare.ie/en/Pages/Farm-Assist.aspx [Accessed April 2017].

[7] DESP (Department of Employment Affairs and Social Protection). See Farm Assist: Part 2 – Farm Inocme or other employment. Available at http://www.welfare.ie/en/Pages/Farm-Assist.aspx [Accessed April 2017].

from farming or leasing is fully assessed with no disregards (DESPb[8]). Net income is calculated by deducting expenses incurred from gross income. Payments under the Farm Retirement Scheme are not taken into account. However, the full value of forest premium payments is taken into account in the means calculation so the pension amount could potentially be reduced or a farmer could be rendered ineligible for a non-contributory pension.

Differential income tax treatment of forest profits

Profits from forests were historically not liable for income tax as the occupation of woodlands for commercial purposes was exempt from income tax. Within the sector this is considered a necessary incentive to overcome the long period of time before significant monetary returns are achieved from forests. However in 2007, Section 17 of the Finance Act (2006) introduced a limit on "specified reliefs" by "high income earners". These specified reliefs included previously exempt income from the occupation of woodlands. Initially, the provision applied to total income in excess of €250,000 in the tax years 2007 to 2010, (whereby the specified relief was limited to 50% of "adjusted income"), before being reduced to €110,000 for tax years 2011 to 2015, and abolished from 2016 onwards. While restricted reliefs could be carried forward (i.e. harvesting could take place over a number of years so that the threshold was not reached), the change in the previously "income tax free" status of forestry was considered to be detrimental to confidence in the sector and was seen as a contributing factor in declining afforestation and lower-than-anticipated timber harvesting. Following representations from the sector, the restriction was removed in the 2016 tax year (Byrne 2016).

Life-cycle framework

From a temporal perspective, a change of land use from agriculture to forest is essentially a permanent land-use change as the legal permission to clearfell and harvest a forest is accompanied by a requirement to replant the harvested area (Forestry Act 2014[9]). The decision also involves moving from an annual agricultural income to a long-term forest investment with delayed revenue. Thus the afforestation decision needs to be modelled within a life-cycle framework to take account of the inter-temporal nature of the land-use change.

Study objectives

In summary, this paper aims to analyse the impact of the inclusion of taxation, charges

[8] DESP (Department of Employment Affairs and Social Protection). See State Pension (non-contributory): Rules-cash income. Available at http://www.welfare.ie/en/Pages/248_State-Pension-Non-Contributory.aspx [Accessed April 2017].

[9] Available at http://www.irishstatutebook.ie/eli/2014/act/31/enacted/en/ [Accessed November 2017].

and benefits in calculating the disposable income arising from the afforestation of a portion of a farm, over the life-cycle of the forest. Results will be generated for typical cattle and dairy farms of varying intensity, reflecting the soil conditions on the farms, while forest income will be generated for a range of forest YCs, also reflecting different productivity contexts.

Methodology

Due to the heterogeneous nature of farm households, the lack of real data in relation to net farm income and the complexity of the policy instruments involved, it is difficult to understand the direct impact of tax, benefit and subsidy policy on farmer income and behaviour. Therefore, in order to assess these policy pressures and impacts directly, a model that simulates policy at the farm level but that can also deal with the complexity of the policy instruments, is required.

Microsimulation: modelling impacts on hypothetical farms

Microsimulation modelling is a micro-scale simulation methodology (see O'Donoghue 2014) that will be used in this context to compare farm incomes for hypothetical farms in order to simulate the effect of alternative tax policies on farm-level outcomes. Hypothetical microsimulation models usually focus on a particular scenario under certain predefined assumptions, allowing an examination of the practical significance of policy reforms.

According to Ciaian et al. (2012), there is a greater need for detailed descriptions of the economic and environmental impact of policies at a disaggregated level (such as the farm), as agricultural policies continue to be increasingly targeted and more farm type-specific. Thus the use of microsimulation models has grown in recent years in agriculture and natural resource policy and many ex-ante assessments of European Commission proposals are undertaken using microsimulation models (Richardson et al. 2014). Burlacu et al. (2014) list the contexts in which hypothetical models are used i.e. for illustrative purposes, validation, cross-national comparisons, replacement of individual farm (micro-scale) data and communication with the public.

O'Donoghue (2014) describes different types of microsimulation models, depending on the analytical dimensions and level of complexity considered.

- Hypothetical models abstract from population and behavioural complexity, focusing on the impact of a policy (or policy change) for stylised units such as representative farms. They are useful for describing the functioning of a policy and are used extensively in international comparisons such as the Agri-Benchmark (Deblitz and Zimmer 2005) or OECD analyses (Martin 1996).
- Static models add population complexity, but ignore behavioural changes that arise as a result of policy changes by looking at 'the day after' impact of policy

reforms (Li et al. 2014). They require representative samples of the relevant population to examine the functioning of policy across the population, without taking into consideration behavioural impacts.

- Behavioural models (Aaberge and Colombino 2014) incorporate behavioural responses across a population following a policy change.

Given the lack of suitable population data on which taxation can be modelled, the analysis was limited to hypothetical farms with particular systems, stocking rates, agricultural soil types and forest productivity (yield) classes. Utilising stylised characteristics, the impact of non-farming and forest policy instruments that are relevant for decision making can be modelled, such as income taxation and means-tested social welfare benefits such as Farm Assist and the old age non-contributory pension. The use of stylised or typical farms has the advantage of highlighting the workings of these policy instruments but the disadvantge of not capturing the full distributional incidence of these instruments. Thus this approach is a net income version of previous gross income analyses of income drivers for planting decisions undertaken by Upton et al. (2013) and Ryan et al. (2014a). While extensively used in other policy realms, the methodology is relatively recent in agricultural and forest economics (O'Donoghue 2014).

The model can be used to consider both budget-constraint and inter-temporal analyses. The microsimulation choices identified by Burlacu et al. (2014) were adapted to specify a stand-alone model using a farm unit basis for analysis. This allowed land-use change from agriculture to forestry to be simulated on a unit area basis, for a variety of farm systems and over the period of a forest rotation. In terms of the budget constraint, as the primary agricultural systems considered were animal-based, the stocking rate (number and type of animals per ha) was considered as the farm unit of variation. The analytical measure used was net farm income.

There is significant micro-unit variability as farms can vary by soil type and agronomic characteristics (which influence both agricultural and forest yield), farm systems (which result in different incomes and costs) and farm level behavioural and skills characteristics (which influence efficiency and farm intensity (stocking rate) considerations). Thus the drivers of the decision to plant can vary considerably across farm types. Therefore in order to understand the economic relative drivers of forestry behaviour, one needs to understand how all of these factors influence the opportunity cost of planting agricultural land, which in turn influences the afforestation decision.

For the purpose of this analysis, it was presumed that afforested areas comprised a relatively minor component of the overall farm operation and to reduce complexity, the initial analysis was undertaken on the basis of the land-use choice on one hectare, in one year (2015). The model choices are summarised in Table 1.

Employing this model, annual forest and livestock subsidies and market incomes before taxation, charges and benefits were applied. Next the model compared net

Table 1: *Model choices for farm afforestation hypothetical model.*

Model parameter	Model choices
Modelling period	2015
Interaction with another model	None – bespoke model used
The unit of analysis	Farm unit
Measurement unit	Ha
Period of analysis	Long-term (5-50 years)
Unit of variation	Stocking rate
Analytical measures	Relative net farm income (agriculture and forestry)

agricultural and forest income, utilising a hypothetical farm framework. In order to account for variability due to soil type and environmental conditions, the model included a sensitivity analysis of changes in stocking rate, disadvantaged area status and forest YC. To estimate the impact on household income, the model also examined the impact of the inclusion of off-farm income on the comparisons.

Lifecycle framework

In order to capture the inter-temporal income from afforestation, it was necessary to utilise a life-cycle framework such as Discounted Cash Flow (DCF). The DCF methodology involves the calculation of the net present value[10] (NPV) to generate the future value of the forest and involved the projection of costs and incomes to the end of the rotation, before discounting them to the present day at a target interest rate (Hiley 1954, 1956), thus Equation 4 defines:

$$NPV = \frac{I}{(1+r)^n} \qquad [4]$$

where n is the number of years into the future that the income amount (I) will be received, or spent if the income amount is negative and r is the discount rate.

In order to examine multi-annual forest life-cycle incomes, a discount factor must be employed. The discount rate chosen for NPV calculations can significantly increase or decrease the NPV of a project. The analysis includes afforestation grant and forest premium subsidies. For an afforestation investment where most costs are incurred during and in the years immediately following establishment (apart from roading costs), and where income only begins from the age of first thinning, a higher discount rate will reduce NPV. The convention is to ignore inflation, as this cannot be predicted. Therefore, the return is regarded as a "real" rate of return. Although the convention for valuation is to generate pre-tax values as per the International

[10] NPV (Net Present Value) is the sum of the present values of incoming and outgoing cash flows over a period of time. Incoming and outgoing cash flows can also be described as income and cost cash flows.

Accounting Standard (IAS 41 – Agriculture[11]), this study goes further to calculate returns, with and without taxation and charges.

In the case of a forest, income and costs can accrue unevenly over the rotation, thus the net present value (NPV) of the whole income stream is the sum of the present values of the annual amounts in the income stream, as presented in Equation 5 (assuming a constant discount rate):

$$NPV = \frac{I_0}{(1+r)^0} + \frac{I_1}{(1+r)^1} + \cdots + \frac{I_n}{(1+r)^n} + \cdots = \sum_{i=1}^{\infty} \frac{I_i}{(1+r)^i} \qquad [5]$$

Relative productivity of agriculture and forestry

In simulating agricultural and forest incomes, it is necessary to utilise methodologies that take the biophysical, as well as the financial and temporal components of the land use change decision into account. Soil productivity as represented by agricultural soil classes and forest YC is an important driver of income for both land uses, thus we follow earlier research by Farrelly et al. (2011) who assigned forest YCs for Sitka spruce to Teagasc NFS soil classes. In addition, the impact of soil on productivity is included in the analysis by modelling a range of stocking rates[12] (livestock densities) and forest YCs.

Generation of agricultural income using farm survey data

The Teagasc NFS undertakes an annual nationally representative farm survey to fulfil Ireland's statutory obligation to provide data on farm output, costs and income to the farm Accountancy Data Network (FADN) of the European Commission. The survey assigns farms to one of six farm systems on the basis of farm gross output from the dominant enterprise[13], as calculated on a standard output basis i.e. specialised dairy, dairy other, tillage, cattle rearing, cattle other and sheep. Using 2015 NFS data (Hennessy and Moran 2016), agricultural incomes were calculated for each farm system and associated NFS soil class on a per-ha basis. This provided the agricultural opportunity cost of afforestation in that year, taking into account the farm system and soil productivity.

Generation of forest income using the ForBES model

The Teagasc ForBES model (Ryan et al. 2016) employs the UK Forestry Commission yield models (Edwards and Christie 1981) to predict future timber outputs based on

[11] European Commission. 2009. International Accounting Standard IAS 41 (Agriculture). Available at http://ec.europa.eu/internal_market/accounting/docs/consolidated/ias41_en.pdf [Accessed July 2017].

[12] Measured as Livestock Units (LU ha^{-1}).

[13] Note that farms may have multiple enterprises, but are categorised on the basis of the dominant enterprise.

species, YC, rotation and thinning regime on a per ha basis. For the purpose of this analysis, the ForBes model simulated forest incomes for Sitka spruce over a range of YCs and generated timber volume outputs from thinnings and clearfells, assuming marginal thinning intensity. The ages of thinning and clearfell were modelled based on current practice where Sitka spruce is grown on a rotation that is less than the age of maximum mean annual increment (mMAI) (as defined by Husch et al. (1982)). The model assumed rotation length to be 80% of mMAI which closely corresponds with financially optimum rotations (Phillips 1998, 2004). In relation to forest costs and revenues, annual maintenance and insurance charges (Teagasc 2015) were included. The costs of harvesting and timber sales were deducted to give net revenue. Financially optimum rotations were used for each YC, varying from 38 to 46 years. Market income was then calculated by applying Coillte (State Forestry Board) conifer roundwood prices.

It is only possible to make direct comparisons between the NPV return on two investments (in this case, land uses) if both investments have the same life spans (Boardman et al. 2011). Thus the NPV needed to be annualised so that it could be expressed on the same basis as annual agricultural returns. The annual equivalised (AE) value was calculated as follows:

$$AE = \frac{r \times NPV}{1-(1+r)^{-n}} \qquad [6]$$

In summary, the model simulation process was as follows: the 2015 agricultural (market and subsidy) income was derived for cattle rearing and dairy farms, for a range of livestock densities. Next, the forest market and subsidy income was simulated for hypothetical forests planted in 2015 for a range of YCs. The ForBES model then simulated total farm (agriculture plus forest) income, incorporating the annual agricultural income (per ha) foregone for the hypothetical farms, as an opportunity cost for each year of a given forest rotation. The discounted cash flow (DCF) methodology was used to calculate the NPV of the ensuing incomes for a range of discount rates.

Agri-Tax model

Finally, once the market plus subsidy incomes for both agriculture and forestry had been generated from the NFS data and the ForBES model respectively, the final analytical step involved modelling these inputs within the Agri-Tax microsimulation framework developed by O'Donoghue (2017). The Agri-Tax model applied the relevant taxation and benefit parameters to generate "disposable" incomes for the hypothetical farms for both agriculture alone and for a combination of agricultural and forest incomes. The Agri-Tax model was further utilised to examine how the individual components of the taxation and benefit measures could affect overall farm income. Scenario analysis was undertaken to examine the differential incomes generated using the market plus subsidy measure and the disposable income measure. The impact of farm system, soil productivity and discount rate were also examined.

Combining the different model components allowed for the calculation of Household Disposable Income (HDI) as follows;

(a) Without income from forestry:

$$HDI = I_{mkt-farm} + S_{farm} + I_{emp} + SW - I_{Tax} - PRSI - USC \quad [7]$$

where $I_{mkt-farm}$ is farm market income, S_{farm} is farm subsidies, I_{emp} is employment income, SW is social welfare and I_{Tax} is income taxation.

(b) With income from forestry:

$$HDI = I_{mkt-for} + S_{for} + I_{mkt-farm} + S_{farm} + I_{emp}E + SW - I_{Tax} - PRSI - USC \quad [8]$$

where $I_{mkt-for}$ is forest market income, S_{for} is forest subsidies, $I_{mkt-farm}$ is farm market income, S_{farm} is farm subsidies, I_{emp} is employment income, SW is social welfare and I_{Tax} is income taxation.

Data and model assumptions

For this analysis, market and subsidy data concerning cattle, dairy and forest enterprises were needed for 2015. Teagasc NFS data (Hennessy and Moran 2016) were used to build a range of hypothetical farms which allowed identification of the particular factors that may impact on income, rather than generating farms to be representative of a particular characteristic. As many Irish farm families are dependent on other income sources, a provision of €25,000[14] gross income to represent a typical annual off-farm/part-time income of either the farmer or the spouse was included.

The annual forest subsidy for Sitka spruce (GPC3[15]) was used. There are limited timber price data for privately-owned forests, therefore price data for Coillte forests as published annually by the Irish Timber Growers Asociation (ITGA 2015) were used[16]. These data represent a large proportion of Irish timber sales and ten-year averages were used to account for annual price fluctuations. As approval to harvest a forest incurs an obligation to replant, replanting costs were also included.

[14] Based on nominal median annual part-time income. Data sourced from SILC (2015). SILC (Survey on Income and Living Conditions). Central Statistics Office. Available at http://www.cso.ie/en/releasesandpublications/er/silc/surveyonincomeandlivingconditions2015/ [Accessed October 2017].

[15] General Planting Category 3: Sitka spruce with 10% diverse conifer: €510 ha^{-1} for 15 years.

[16] Note that these data may not accurately represent the sale of small diameter timber (pulpwood) as much of this assortment is retained for processing by Coillte.

Taxation

The tax rates used in the Agri-Tax model are from 2015 and are listed in Table 2. Since only farm forestry was of interest, charges for PRSI and USC were applied at rates relevant to farmers. As the vast majority of farmers are self-employed, PRSI was paid at a rate of 4% on gross income. USC started at 1.5% on the first €12,012 of income, 3.5% on the next €5,564, 7% on the next €52,468 and 8% on the balance of income. It was assumed that the farmer was married (without children) and that tax/exemption rates remained the same from 2015 onwards.

The position in relation to income taxation for agriculture and forestry is quite different. As a financial incentive for greater afforestation and for better utilisation of existing forests, this land use has historically enjoyed a preferential position in relation to taxation. While income from forests must be declared in tax returns and is liable for PRSI and USC, profits from the "occupation of woodlands" were not liable for income tax until 2007 when a restriction on untaxable income was imposed. This restriction was removed for the 2016 tax year, but it's potential financial impact over the lifetime of a forest crop was examined.

Results

Initially, descriptive statistics were generated which illustrate (in general terms) how the components of the tax and transfers system in Ireland operate in relation to agricultural and forest income. Following this, the hypothetical farms were used to assess how these financial instruments impact of such typical farms, before extending the analysis to examine the impacts over a forest rotation.

General impact of fiscal instruments

Figure 1 describes the general direct taxation and contribution schedule for a single cattle farmer with average income, aged 62. Given an allowance of €5,000, the farmer pays more self-employed PRSI initially at a flat rate of 4%. The USC increments in bands up to €100,000. Direct income tax has two bands (20% and 41%) and has an optional joint system, but with less than full sharing of the standard rate band plus a number of tax credits. The combination of the allowances and variable rates, gives the non-linear shape observed here. As forest income, (subsidies and market) was not

Table 2: *Key income-tax parameters (correct for 2015) used in the modelling process.*

Year	2015
Income tax (low rate)	20%
Income tax (high rate)	41%
PRSI	4%
Universal Social Charge (USC)	1.5 – 8%
Married income tax credit	€3,300

taxable (in general), there was potentially a generous financial incentive for planting a portion of the farm.

In 2007, the High Income Individuals Restriction introduced a complex process to limit allowable tax relief on forest incomes that exceeded a certain limit. The threshold amount of €125,000 was the limit of adjusted income (taxable income plus income at which the relief applied) over which the tax-payer could claim all reliefs. Once the threshold income exceeded this limit, or if the value of the reliefs exceeded 20% of the adjusted income, the limit was imposed. In this case income that exceeded a threshold of €80,000 was added to the tax base.

The dotted line in Figure 2 describes the operation of the restriction in relation to the income taxation of a dairy farmer with a farm forest (YC 24), who has varying hectares of land in the year of harvest. Initially as the forest income is not taxable, the level of income taxation does not increase. Thus the continuous line, which describes the income taxation rate as a share of total farm income (agriculture plus forestry) decreases, as forestry harvest income increases. Once the restriction was applied however, forest taxation rises, causing the income taxation rate to rise.

Farms on low income are entitled to Farm Assist. Figure 3 illustrates the operation of Farm Assist which shows that as income increases, the Farm Assist payment decreases. Unlike other means-tests, the Farm Assist assessment is not based on total net income. While PRSI is deducted for employment income, it is not deducted from

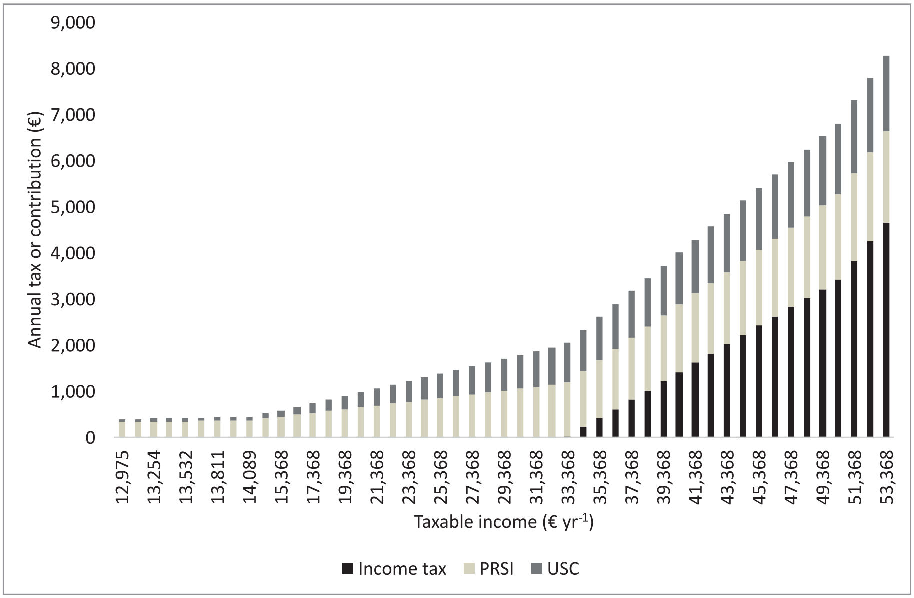

Figure 1: *Direct taxation and contribution schedule for a single cattle farmer with average income, aged 62 .*

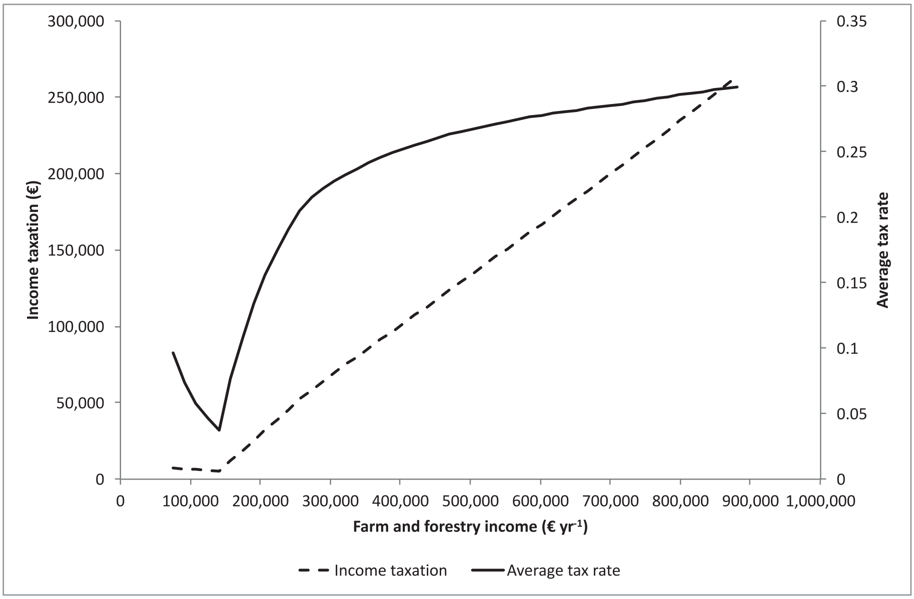

Figure 2: *Impact of high earners restriction (2015) on the income taxation of a dairy farmer with a farm forest (YC 24), who has varying hectares of land in the year of harvest.*

farm income, and USC and income taxation are also not deducted.

Impact of fiscal instruments on hypothetical farms in one year (2015)

Combining the different types of income and policy rules that apply to farmers who plant land, the analysis next reports the budget constraints generated by the model for a typical (hypothetical) cattle farm, which result from the changing components of disposable income. The complexity of the operation of the fiscal policies in relation to land use is illustrated in Figures 4 (for a working age farmer) and Figure 6 (retirement age farmer). Here the effect of adding hectares of forestry and adding income from off-farm employment are examined but the first 10 bars of both charts represent the addition of one to ten hectares of forestry. In the remaining bars of the chart, the planted area is held constant at ten hectares, while off-farm income is increased in increments of €1,000.

The typical farm examined is a cattle farm with a stocking rate of 0.7 LU ha^{-1} with YC 14 land. At this low stocking rate, a farming couple can receive Farm Assist of up to €16,309 and a single farmer can get €9,802 (less means). Figure 4 illustrates that for this typical farm, as forest income increased, gross income increased since forest income was higher than agricultural income per ha at this stocking rate. However, in 2015, the withdrawal rate for Farm Assist was 100%, so a euro-for-euro reduction in Farm Assist can be seen for every extra euro of forest income. At this point PRSI and USC were being subtracted from disposable income and income taxation was

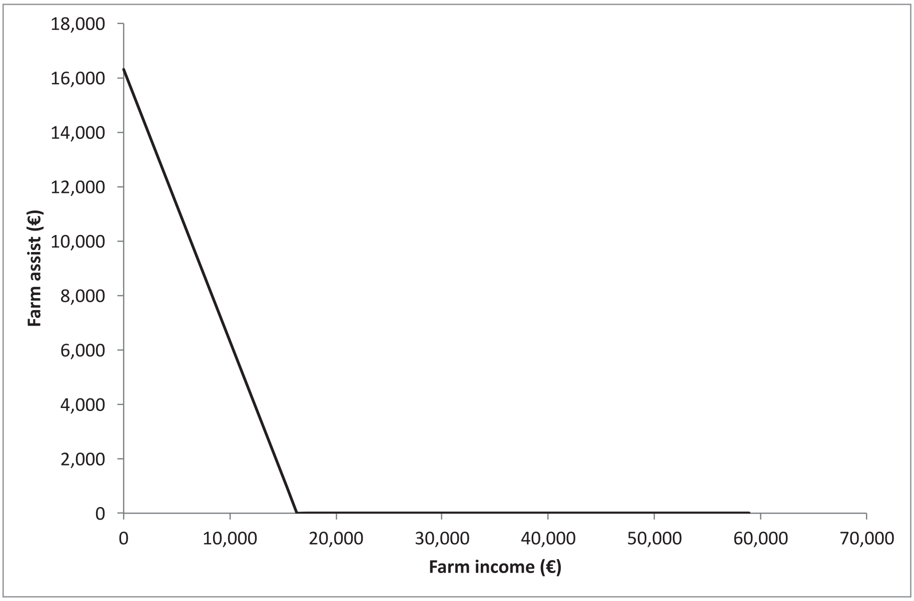

Figure 3: *Reduction in level of Farm Assist payment as farm income increases (2015).*

subtracted later, so that the top line of the graph represents the combined total, i.e. disposable income. The presence of off-farm income at this level largely eliminated the entitlement to Farm Assist means-tested income. Without off-farm income, additional income from forestry was lost through a reduction in Farm Assist. However if Farm Assist had already been reduced through the presence of off-farm income, then the gains from foresty would be additional.

In addition, as the means-test depends on gross income (not including taxation, PRSI and USC), and because PRSI and USC are charged on forest income, the effects of adding forest income and off-farm income are examined at both ends of the income distribution. This shows the financial effect of replacing agriculture with forestry as agricultural income falls while forest (premium) income rises and Farm Assist falls off slightly, reducing the financial incentive. This is illustrated further in Figure 5 which zooms in on the loss of Farm Assist at the lower end of the income distribution. In 2015 the withdrawal rate for employment income is 60% and so disposable income increased as employment income increased.

From 2017, the withdrawal rate for farm (and forest) income has been reduced to 70%. While this means that in future disposable income will rise with forest income, 74.5% of extra forest income will be lost through the Farm Assist means-test, PRSI and USC. Thus, for farmers whose (low) agricultural income should make planting worthwhile, because they are likely to be in receipt of Farm Assist (unless they have an off-farm job), the addition of forest income actually reduces their Farm Assist

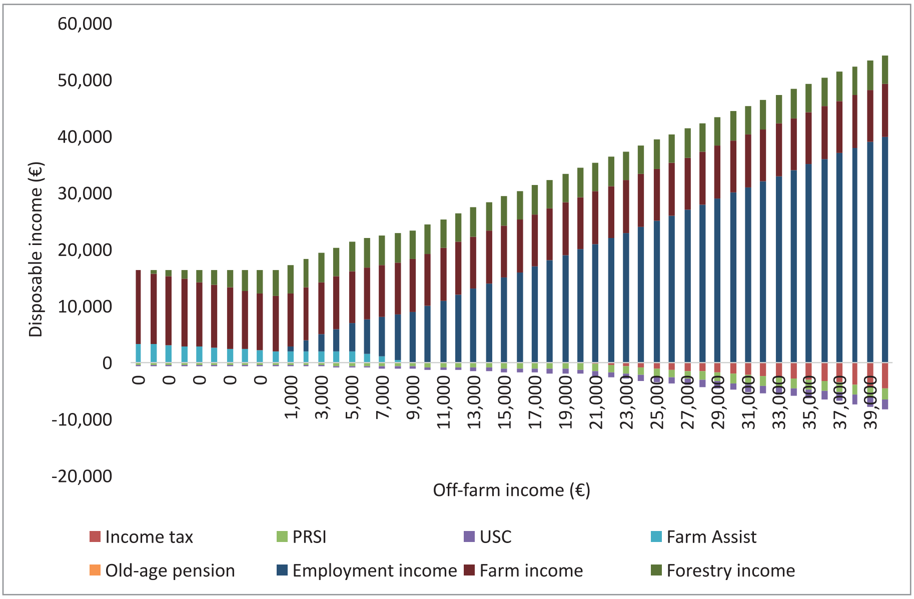

Figure 4: *Effect of changing forest area and off-farm income on disposable income for a cattle farm with stocking rate of 0.7 LU ha^{-1} and YC 14 land (assumig owners of working age).*

payment. While the reduction in Farm Assist is small, it may still be perceived negatively by farmers.

Figure 6 presents the modelled budget constraint diagram for retirement-age farmers, replacing Farm Assist with a means-tested State pension. If a farmer was in receipt of a contributory pension, then the pension payment would be at a flat rate, regardless of income. It should be pointed out however, that older farmers who plant land could potentially suffer a reduction in old-age pension, due to the inclusion of forest income in the means assessment for a non-contributory pension, which is why the flat segment occurs in Figure 6. While PRSI is not paid by individuals of pension age, USC is, so a slight fall can be seen in disposable income at low levels of income after planting.

Impact of fiscal instruments on life-cycle returns for a hypothetical farm

The analysis has so far considered the general impact of policy in relation to income. Next the life-cycle impact of fiscal policies on agricultural and forest income is incorporated. In order to examine a range of productivity classes, a range of agricultural livestock densities and forest YCs were used. Cattle rearing farms of 35 ha and dairy farms of 50 ha with low, medium and high stocking rates were examined, reflecting varying intensities of production. In relation to farm systems, while the cattle farms had higher subsidies (particularly at higher stocking densities) dairy farms across all stocking densities had considerably higher outputs,

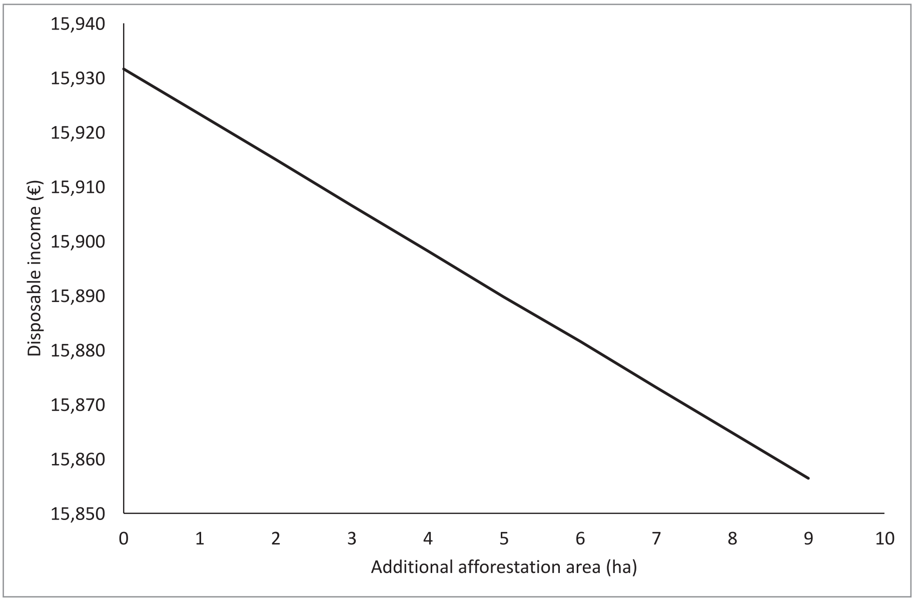

Figure 5: *Modelled annual disposable (€) income for a couple of working age, related to level of afforestation.*

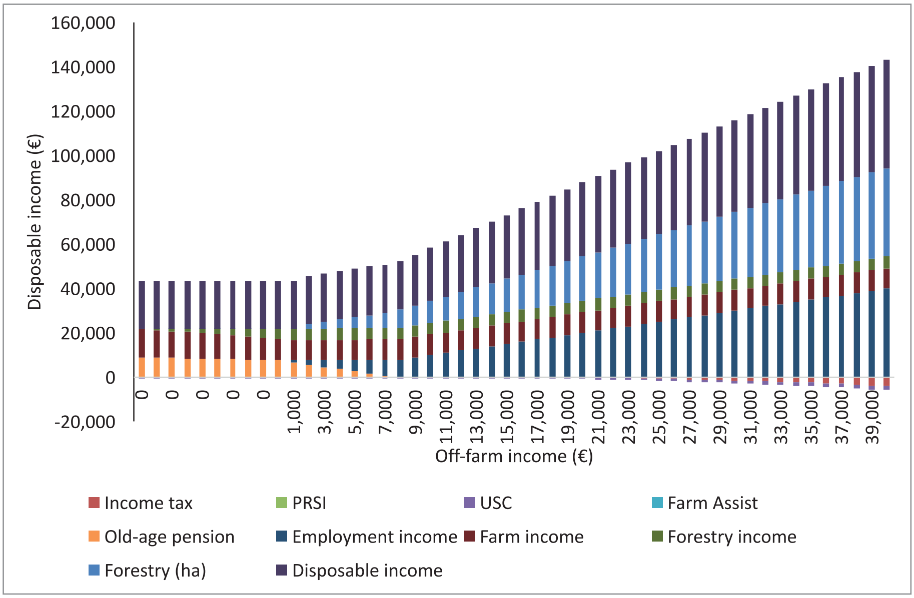

Figure 6: *Effect of changing forest area and off-farm income on disposable income for a cattle farm with stocking rate of 0.7 LU ha*$^{-1}$ *and YC 14 land (pension age). The first 10 columns represent an increase in forest area from 0 to 10 ha, required to show the impact of a land use change from agriculture to forestry. The remaining columns represent an increase in off-farm income, necessary to highlight the functioning of the wider tax-transfer system.*

were more profitable and thus had a higher opportunity cost of planting than cattle farms.

The forest market income from planting 10 ha for a range of YCs was also examined. Higher YC sites generated greater annual income as they produced greater volumes of timber over shorter rotations. Although an explicit spatial analysis was not undertaken in this paper, different soil codes or YCs were examined, which have spatial patterns as seen in Table 1 in the Appendix.

In order to incorporate the inter-temporal dimension of farm afforestation, the components of the life-cycle return from forestry were investigated. Figure 7 shows a comparison between three income measures, namely market income, gross income (market plus subsidies) and disposable income. This analysis specifically considers a 35-ha cattle farmer with a stocking rate of 0.7 LU ha^{-1} who has an off-farm job (with a typical part-time wage), who plants a 10-ha YC 20 forest in 2015.

The model assumes the farmer to be 45 in the year of planting so that he/she can conceivably benefit from life-cycle market income. While the typical age at which farmers plant varies and can be substantially higher, modelling planting at an older age in a hypothetical farm simulation model is challenging as it would require a weight to be placed on the welfare of future generations, in relation to the value of a bequest. It is generally accepted that the loss of flexibility of land use after planting can be a negative consequence of the afforestation decision (Ryan et al. 2014b) even if farmers would gain personally, however the inter-generational transmission of wealth

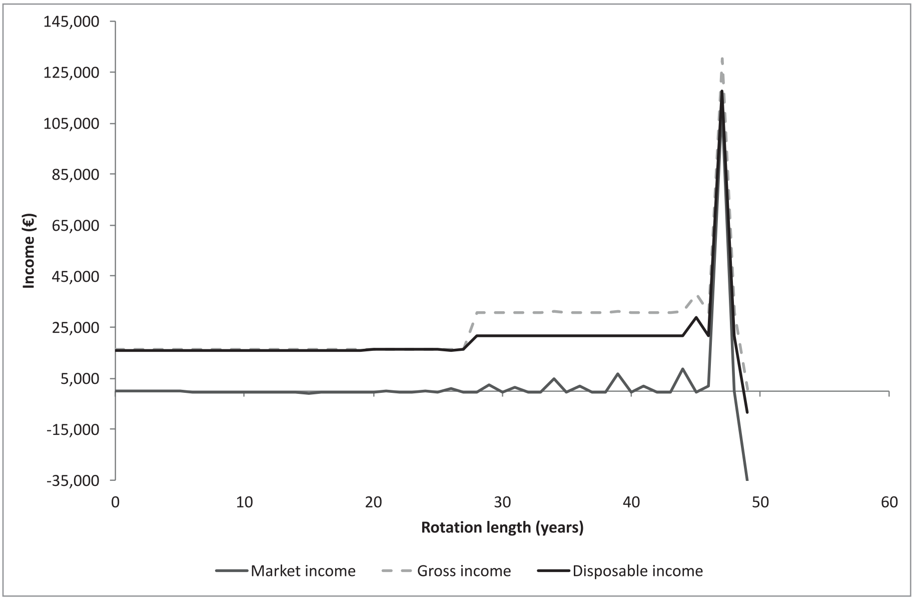

Figure 7: *Life-cycle comparison of income measures over time: market income, gross income and disposable income.*

is beyond the scope of this study which focused on understanding how policy drivers such as tax, PRSI and social welfare influenced the financial incentives to plant.

As such, the choice of age is unimportant as the main farm and forest policies (the factors that influence change in the numerator and denominator) are not age-dependent. The policies that depend on age, namely Farm Assist, old-age pension, the age cut-off in PRSI and age-related tax credits/tax exemptions, apply to both the numerator and denominator. The same rules are applied to both income net of agricultural farming and net of farming with agriculture and forestry income and as such, the impact of modelling different ages will not substantially alter the relative income differential between choices, other than at the margin through the progressivity of the system. Therefore this study focused on a single age.

The life-cycle considered incorporated non-contributory means-tested old-age pension as all farms were modelled without pension contributions. The income spike at year 41 represents the forest harvest income, while the dip in year 43 is the cost of replanting. The blips in the earlier years represent thinning revenues. In general it was found that the market income was only marginally negative, due to annual maintenance costs. Gross income was positive due to forest premium payments, farm direct payments and Farm Assist. In Table 3 this analysis was extended to different types of farms, combining the different incomes over the life-cycle of the forest and considering both cattle rearing and dairy farms. AE was reported for farms with different stocking rates and for different discount rates (3, 4 and 5%) keeping forest YC constant at YC 20.

The effect of the choice of discount rate used is immediately evident as the lower discount rate results in the highest life-cycle incomes. In examining the differences in farm intensity as represented by varying the livestock density, a number of trends are evident:

- For cattle farms with low stocking (0.7 LU ha^{-1}), the income from farms with forests is higher than the income from farming alone, regardless of the income measure used.
- Here the importance of Farm Assist is evident as it compensates for the low market plus subsidies income, thus the disposable income is higher on these farms.
- As stocking rate on the cattle farms increases to 1.3 LU ha^{-1}, the conclusions differ depending on whether the disposable income or market income plus subsidies measures are utilised. For cattle farms of medium intensity, the agricultural income is highest at the 3% discount rate, except in the final harvest year. Harvest income alone does not compensate for the long-term difference between forest income and agricultural income, however a combination of Farm Assist and the old age means-tested pension, compensate for the loss of income during the years of lower agricultural income. Thus, the harvest

***Table 3:** Comparison of annual equivalised (AE) NPV[a] of disposable income and market plus subsidies for farming alone and farming plus 10 ha of forest for a range of discount rates (3%, 4%, 5%).*

System	**Cattle rearing**			**Dairy**		
Stocking rate	0.7	1.3	1.7	1.7	1.9	2.1
Yield Class	20	20	20	20	20	20
Disposable income (€)						
Forestry						
0.03	22,114	27,558	35,145	49,281	56,601	64,067
0.04	21,253	26,084	33,390	47,941	55,084	62,371
0.05	20,523	24,817	31,878	46,811	53,801	60,934
Farming						
0.03	20,848	27,394	37,475	51,990	60,631	69,420
0.04	20,270	26,266	36,036	50,834	59,287	67,886
0.05	19,773	25,286	34,788	49,845	58,138	66,573
Difference[b]						
0.03	1,266	164	-2,330	-2,708	-4,030	-5,352
0.04	983	-182	-2,646	-2,893	-4,203	-5,515
0.05	750	-469	-2,909	-3,035	-4,336	-5,639
Market income + subsidies (€)						
Forestry						
0.03	11,378	22,266	29,524	52,236	60,356	68,477
0.04	11,033	21,684	28,784	51,003	58,947	66,891
0.05	10,754	21,202	28,168	49,965	57,758	65,551
Farming						
0.03	9,111	24,354	34,516	58,788	68,938	79,088
0.04	8,913	23,825	33,766	57,510	67,440	77,370
0.05	8,744	23,372	33,124	56,418	66,159	75,901
Difference[b]						
0.03	2,267	-2,088	-4,991	-6,551	-8,582	-10,612
0.04	2,119	-2,141	-4,981	-6,507	-8,493	-10,479
0.05	2,010	-2,170	-4,956	-6,453	-8,402	-10,350

[a] The AE value presents the life-cycle Net Present Value as an annual equivalent, thus making it comparable with annual agricultural incomes.

[b] A negative difference indicates that the income from farming alone is higher than when 10 ha of forest is substituted for 10 ha of farm income.

income is higher than the disposable income losses, particularly as this income stream is tax free.

- Conversely for cattle farms with a high stocking rate of 1.7, the AE for farming alone is higher than for farming plus forestry. This is also the case with dairy farms, irrespective of stocking rate, income measure or the discount rate applied. This reflects the greater opportunity cost that more intensive farmers incur in foregoing the annual income from 10 ha of an intensive cattle rearing or dairy enterprise.

In relation to the magnitude of the difference between the income measures when forest income is included, the story is very different for cattle rearing and dairy farms. On less intensive cattle farms with low stocking density, the difference is positive (indicating that farm plus forest income is higher), however the difference between the measures is relatively small. As the level of farming intensity increases, so too does the gap between the measures. As stocking rate increases for both cattle and dairy farms, the negative difference between the disposable income and market and subsidies measures increases monotonically. There are essentially two factors driving this trend. As intensity increases, so does agricultural income foregone, i.e. the opportunity cost is largely driving the market and subsidies measure. However, in relation to the disposable income measure, the gap between the farm and forest incomes is much smaller. This is because the tax-free nature of the forest income means that the reduction in income tax mitigates the high agricultural opportunity cost to a large extent, indicating the importance of the income tax measures at the higher end of the income distribution.

The impact of a range of forest yield classes on disposable and market plus subsidy incomes is further illustrated in Table 4. For all dairy scenarios, both disposable income and market plus subsidies measures are negative, regardless of agricultural stocking rate or forest YC at a discount rate of 4%.

Across the cattle rearing scenarios the results show consistent trends. At lower stocking rates, the inclusion of 10 ha of forest is increasingly positive as YC increases, for both income measures. However at the higher stocking rate, agricultural income is higher for both measures. As with the dairy scenarios, the scale of the negative income (from the inclusion of 10 ha of forest), decreases for the highest forest YC.

This is consistent with previous distributional analysis (Ryan and O'Donoghue 2016) which shows that forestry is not financially competitive with dairy farming (even on poorer soils) due to the high level of opportunity cost that would be incurred in a land use change to forestry. It is interesting though that the scale of the negative incomes related to the inclusion of forestry reduces for YC 24, reflecting the greater forest productivity at higher YCs. It should be noted that in reality, farmers may choose to harvest timber earlier to avail of higher timber prices and shorter rotation lengths, thereby increasing forest income, however this analysis is based on standardised forest yield models and average timber prices. While we emphasise that these calculations are for hypothetical stylized farms of different types and stocking rates, it does highlight the important point that the financial impact of planting varies when overall farm disposable income is taken into consideration, rather than just examining the traditional market plus subsidies measure.

Table 4: *Annual equivalised NPV [a] of the difference in disposable income and market plus subsidies, between Farm Income and Farm plus Forest Income for a range of Yield Classes (discount rate = 4%).*

System	**Cattle Rearing**			**Dairy**		
Stocking Rate	0.7	1.3	1.7	1.7	1.9	2.1
Yield Class	**14**	**14**	**14**	**14**	**14**	**14**
Disposable income (€)	324	-2,205	-4,257	-2,613	-3,819	-4,962
Market plus subsidies (€)	154	-4,830	-8,152	-5,919	-7,684	-9,449
Yield Class	**18**	**18**	**18**	**18**	**18**	**18**
Disposable income (€)	473	-316	-3,177	-2,259	-3,483	-4,651
Market plus subsidies (€)	2,080	-1,717	-4,248	-5,627	-7,429	-9,232
Yield Class	**20**	**20**	**20**	**20**	**20**	**20**
Disposable Income (€)	750	-469	-2,909	-3,035	-4,336	-5,639
Market plus subsidies (€)	2,010	-2,170	-4,956	-6,453	-8,402	-10,350
Yield Class	**24**	**24**	**24**	**24**	**24**	**24**
Disposable income (€)	1,044	-153	-2,688	-2,991	-4,358	-5,725
Market plus subsidies (€)	2,519	-1,717	-4,542	-6,654	-8,699	-10,744

[a] Negative values indicate that farm income was greater than farm plus forest income.

The difference in the period of analysis of the annual equivalised NPV and the period of analysis of a means-tested social protection instrument or benefit is also worth noting. Means-tested benefits are paid when incomes are low in a particular year. They are not based on life-cycle total earnings. Thus a farmer with low stocking rate and income over a long period (due to forest subsidies being lower than agricultural income), may be compensated if their income is low enough. Yet when they make a major financial gain on harvesting, although it is likely to reduce or eliminate the benefit in that year, it does not impact the benefits from other years. This is one of the main reasons why disposable income is higher sometimes for forestry, while agricultural market and subsidy incomes are higher when taxation and benefits are not taken into consideration.

Conclusions

This paper examines the potential impact of taxation and benefits on disposable income for a farm family considering planting some of their agricultural land. The methodology and model adapted for this analysis extend the literature on the economic returns from farm afforestation to incorporate the impact of fiscal measures such as farm taxation and benefits. The analysis builds on previous work by McCormack et al. (2014) who used a hypothetical model to examine how subsidy policy created behavioural pressures amongst Irish beef farmers, and Ryan et al.

(2014a) who developed a hypothetical forest subsidies microsimulation model. This model is a single country microsimulation model taking hypothetical farm units as the unit of analysis, with a policy scope of the impact of taxation/transfers on agricultural and forest incomes. The framework is similar to other models used for comparative purposes such as the OECD "Making Work Pay" type analyses (Martin 1996).

While forest YC (and prevailing market prices) largely determine the profitability of forest enterprises, in the context of a land use change from agriculture, the net benefit/deficit of farm afforestation is determined by a combination of the soil productivity for agriculture and forestry, the magnitude of the opportunity cost, the presence of off-farm income in the household and the consequent tax and benefit treatment of the overall farm household income. While much of the recent literature agrees that there are cultural, attitudinal and lifestyle barriers to the uptake of farm forestry (Frawley 1998, Duesberg et al. 2013), which are exacerbated by the loss of flexibility of land use as a result of the permanent nature of afforestation in Ireland, the financial return is also important as evidenced in previous analysis (Ryan and O'Donoghue 2016) and by O'Connor and Kearney (1993) who conclude that farmers will not undertake afforestation unless it is more lucrative than farming.

Essentially, governments use financial incentives to encourage individuals to undertake measures that achieve strategic aims (for example Food Harvest 2020 targets). The main policy instruments available to governments are financial e.g. subsidy-based incentives or taxes and benefits. Entering financially incentivised schemes reduces uncertainty around income for farmers, thus reducing their perceived economic risks (Koundouri et al. 2009). However, in a recent survey of farmers who had not planted, Duesberg et al. (2013) conclude that the reason why forestry was not an option is that it was not regarded as farming.

The desire to continue farming is not unique to Ireland. Gorton et al. (2008) examined farmer attitudes in EU countries and concluded that even after payments were decoupled from production with the consequence that farmers who were making a loss from the market could reduce their stocking rate (without losing payments), most farmers maintained their productivist objectives and preferred to maintain their farming lifestyle, even when this resulted in a financial loss. Borrowing from behavioural economics theory, this introduces the concept that a "compensating differential" (Carpenter et al. 2015) is necessary to provide a "nudge" for farmers to undertake the change from farming to forestry with which they have less familiarity and which may not coincide with their lifestyle (Ryan and O'Donoghue 2016b).

This is consistent with a study of NFS farms that planted forests over a 30-year period (Ryan and O'Donoghue 2016a), whose analysis suggested that planting land matched different lifestyle objectives for different types of farmers. For example, younger intensive farmers maintained stocking rates after planting, indicating that they optimised land use by planting their marginal land; part-time farmers reduced their agricltural area and increased stocking rates on the remaining land, optimising their time; while the largest cohort of (older) farmers reduced their stocking rate after planting. This study also showed that financial drivers are not significant at the margins but are significant when there is a large qualitative difference between agricultural and forest incomes. This arises at the extremes of the distribution as those with the highest gains (and large farm areas with access to spare land) are most likely to plant, while farms with the lowest gains are least likely to plant.

Building on these previous analyses, this study illustrates the importance of the benefits and income-tax components of disposable income in the relative returns from planting 10 ha of forest on hypothetical extensive and intensive cattle and dairy farms. From a household welfare perspective, the inclusion of benefits and taxation in the calculation of life-cycle farm and forest income can impact on the long-term financial welfare of the household, particularly at the extremes of the income distribution.

For low income farms, if income from forestry is less than agricultural income in the early stage of the forest life cycle, social protection instruments such as Farm Assist can mitigate the short-term income reduction. However, for those farms that are most likely to benefit from planting i.e. where forest income is higher than agricultural income, then the means test for social protection instruments can reduce the incentive to plant. While this may not directly affect the planting rate, it has an effect on income; i.e. why would farmers choose to plant land and forego agricultural income and lifestyle flexibility for only a marginal financial gain?

It should be noted here that the change in the Farm Assist withdrawal rate for 2017 will alleviate this, however, this change also means that the income range over which Farm Assist is paid, increases from €16,309 for a couple to €23,299. As the average weighted income for cattle systems in 2015 was just over €15,000, this income range accounts for over three quarters of NFS cattle farmers without off-farm income (Hennessy and Moran 2016). This essentially gives rise to an increase in the marginal effective tax rate for low income farms, without other (non-means tested) income sources such as off-farm income or contributory pensions.

More generally for higher income farms, the favourable tax treatment of forestry income reduces the gap between the higher income from agriculture and the lower forestry income. However, this gain may be marginal unless these farms are large with spare livestock carrying capacity. In such cases, high-income farmers benefit from a win-win situation of being able to increase stocking rates (and income), while also benefiting from the tax-free forest income.

From a policy perspective, this analysis supports the recommendations of the

Forest Land Availability Implementation Group which recognises the potential importance of taxation and benefits in relation to their impact on disposable income when making the decision to plant. The results illustrate the re-distributive nature of the Irish tax/benefits system, as benefits can be very significant at the bottom of the income distribution whereas taxation narrows the gap at the top of the distribution. The analysis also shows that even if the level of disposable income is higher for agriculture on more intensive farms, the use of a disposable income measure in analysing the returns from farm afforestation, provides valuable insights in relation to how financial policy affects different farm systems with varying levels of farming intensity. Further research is required to estimate "cut"' points at which changes in taxation or benefit thresholds and increased level of uptake of benefits, could bring about a gain at farm level from the inclusion of forestry in overall farm income.

References

Aaberge, R. and Colombino, U. 2014. Labour supply models. In *Handbook of Microsimulation Modelling*, Emerald Group Publishing Limited. pp 167-221.

Ahearn, M., Johnson, J. and Strickland, R. 1985. The distribution of income and wealth of farm operator households. *American Journal of Agricultural Economics* 67: 1087-1094.

Andersen, F.G., Asheim, L.J., Mittenzwei, K. and Veggeland, F. 2002. *Taxation of Agriculture in Selected Countries*. Norwegian Agricultural Economics Research Institute, Oslo.

Bateman, I.J., Lovett, A.A. and Brainard, J.S. 2005. *Applied Environmental Economics – A GIS Approach to Cost Benefit Analysis.* University Press, Cambridge.

Behan, J. 2002. Returns from farm forestry vs. other farm enterprises. Paper presented at the IFA Farm Forestry Conference, 8th November 2002, Limerick, Ireland.

Bhaskar, A. and Beghin, J. C. 2009. How coupled are decoupled farm payments? A review of the evidence. *Journal of Agricultural and Resource Economics* 34: 130-153.

Boardman, A.E., Greenberg, D.H., Vining, A.R. and Weimer, D.L. 2011. *Cost-Benefit Analysis: Concepts and Practice* (4th ed.). Prentice Hall, Upper Saddle River, NJ.

Breen, J., Clancy, D., Ryan, M. and Wallace, M. 2010. Irish land use change and the decision to afforest: an economic analysis. *Irish Forestry* 67: 6–20.

Burlacu, I., O'Donoghue, C. and Sologon, D.M. 2014. Hypothetical models. In *Handbook of Microsimulation Modelling.* Ed. O'Donoghue, C., Emerald Group Publishing Limited Bingley 23-46.

Buslei, H.S., Bach, M. and Simmler, M. 2014. Firm level models. In *Handbook of Microsimulation Modelling.* Ed. O'Donoghue, C., Emerald Group Publishing Limited Bingley. pp 275-304.

Byrne, D. 2016. *ITGA Yearbook*. Irish Timber Growers Association. Dublin.

Carpenter, J., Matthews, P.H. and Robbett, A. 2015. *Compensating Differentials in Experimental Labor Markets*. IZA Discussion Paper No. 8820. Available at http://ftp.iza.org/dp8820.pdf [Accessed November 2017].

Ciaian, P. and Kancs, D.A. 2012. The capitalization of area payments into farmland rents: micro evidence from the new EU member states. *Canadian Journal of Agricultural Economics/Revue Canadienne d'Agroeconomie* 60: 517-540.

Collier, P., Dorgan, J. and Bell, P. 2002. *Factors Influencing Farmer Participation in Forestry*. COFORD. Dublin.

DAFM 2013. Helpsheet – Terms and conditions for the 2013 EU Single Payment Scheme (SPS) and other 2013 area-based schemes. Department of Agriculture, Fisheries and Marine, Dublin. Available at https://www.agriculture.gov.ie/media/migration/farmingschemesandpayments/singlepaymentsscheme/2013/2013SPSTandC180413.pdf [Accessed November 2017].

DAFM. 2015a. Food Wise 2025. *A 10-year Vision for the Irish Agri-Food Industry*. Department of Agriculture, Fisheries and Marine, Dublin.

DAFM. 2015b. *Forestry Programme 2014-2020: Ireland*. Forest Service of the Department of Agriculture, Food and Marine. Dublin.

Deblitz, C. and Zimmer, Y. 2005. Agri benchmark Cash Crop: a standard operating procedure to define typical farms. *Braunschweig: Agri benchmark*.

Duesberg S., O'Connor, D. and Ní Dhubháin, Á. 2013. To plant or not to plant—Irish farmers' goals and values with regard to afforestation. *Land Use Policy* 32: 155–164.

duQuesne Ltd. 1993. *EC Funds and Irish Forestry*. Thematic evaluation of EC co-financed forestry measures in Ireland. duQuesne Ltd. Economic and Environmental Consultants. Dublin.

Edwards, P.N. and Christie, J.M. 1981. *Yield Models for Forest Management*. Forest Commission Booklet 48, HMSO, London.

Farrelly, N., Ní Dhubháin, Á. and Nieuwenhuis, M. 2011. Modelling and mapping the potential productivity of Sitka spruce from site factors in Ireland. *Irish Forestry* 68: 23-40.

Forestry Commission. 2013. *Forest Statistics*. Available at Forestry Commission. 2013. *Forest Statistics*. Available at https://www.forestry.gov.uk/website/forstats2013.nsf/lucontents/42e8ae2f58ef29c980257be30059e349 [Accessed Jan 2015].

Frawley, J.P. 1998. Farmers' attitudes towards forestry as a farm enterprise in Ireland. In *Forestry in the Context of Rural Development*. Ed. Wiersum, F.K., Proceedings of the Final Scientific COST Action E3, May 1998, Villa Real, Portugal.

Gorton, M., Douarin, E., Davidova, S. and Latruffe, L. 2008. Attitudes to agricultural policy and farming futures in the context of the 2003 CAP reform: a comparison of farmers in selected established and new Member States. *Journal of Rural Studies* 24: 322-336.

Hemme, T., Deblitz, C., Isermeyer, F., Knutson, R. and Anderson, D. 2000. The International Farm Comparison Network (IFCN) objectives, organisation and first results on international competitiveness of dairy production. *Züchtungskunde* 72(6): 428-439.

Hennessy, T. and Moran, B. 2016. *Teagasc National Farm Survey Results 2015*. Teagasc, Athenry.

Herbohn, J., Emtage, N., Harrison, S. and Thompson, D. 2009. The Australian Farm Forestry Financial Model. *Australian Forestry* 72(4): 184–194.

Hiley, W.E. 1954. *Woodland Management*. Faber and Faber, London.

Hiley, W.E. 1956. *Economics of Plantations*. Faber and Faber, London.

Hill, B. and Cahill, C. 2007. Taxation of European farmers / La fiscalité des agriculteurs européens / Die Besteuerung der Landwirte in Europa. *EuroChoices* 6: 44-49.

Husch, B., Miller, C.I. and Beers, T.W. 1982. *Forest Mensuration*. Wiley, New York. p 402.

ITGA (Irish Timber Growers Association). 2015. *Irish Timber Growers Yearbook*. Dublin.

Koundouri, P., Laukkanen, M., Myyra, S. and Nauges, C. 2009. The effects of EU agricultural policy changes on farmers' risk attitudes. *European Review of Agricultural Economics* 36: 53–77.

Lewis, P.E., Hall, N.H., Savage, C.R. and Kingston, A.G. 1988. Taxation, cost of capital and investment in Australian agriculture. *Australian Journal of Agricultural Economics* 32: 15-21.

Li, J., O'Donoghue, C., Loughrey, J. and Harding, A. 2014. Static Models. In *Handbook of Microsimulation Modelling.* Emerald Group Publishing Limited, Bingly. pp. 47-75.

Martin, J.P. 1996. Measures of replacement rates for the purpose of international comparisons: a note. *OECD Economic Studies* 26: 99-115.

McCarthy, S., Matthews, A. and Riordan, B. 2003. Economic determinants of private afforestation in the Republic of Ireland. *Land Use Policy* 20: 51-59.

McCormack, M. and O'Donoghue, C. 2014. Policy incentives as behavioural drivers of beef enterprises in Ireland: Where are the kinks? Paper presented at European Association of Agricultural Economists. Ljubljana, Slovenia. 25-28th August 2014.

McKillop, D. and Kula, E. 1988. A planting function for private afforestation in N. Ireland. *Journal of Agricultural Economics* 39: 133-141.

O'Connor, R. and Kearney, B. 1993. Economic issues in Irish forestry. *Journal of the Statistical and Social Inquiry Society of Ireland* XXVI(V): 179-209.

O'Donoghue, C. 2014. *Handbook of Microsimulation Modelling*. Emerald Group Publishing Limited, Bingley.

O'Donohgue, C. 2017. *Farm Level Microsimulation Modelling*. MacMillan, Palgrave.

Phillips, H. 1998. Rotation length, thinning intensity and felling decision for blue areas. Report Commissioned by Coillte Forests, Coillte, Dublin.

Phillips, H. 2004. Review of rotation lengths for conifer crops. Report Commissioned by Coillte Forest, Coillte, Dublin.

Richardson, J.W., Hennessy, T. and O'Donoghue, C. 2014. Farm-level models. In *Handbook of Microsimulation Modelling*, Emerald Group Publishing Limited, Bingley. pp. 505-534.

Ryan, M., O'Donoghue, C. and Phillips, H. 2016. Modelling financially optimal afforestation and forest management scenarios using a bio-economic model. *Open Journal of Forestry* 6: 19-38.

Ryan, M. and O'Donoghue, C. 2016a. Heterogeneous economic and behavioural drivers of the farm afforestation decision. Conference paper presented at 18th BIOECON conference. Kings College, Cambridge. 14-16th September 2016. Available at http://www.bioecon-network.org/pages/18th_2016/Ryan.pdf [Accessed May 2017]

Ryan, M. and O'Donoghue, C. 2016b. Socio-economic drivers of farm afforestation decision-making. *Irish Forestry* 73: 96-121.

Ryan, M., McCormack, M. O'Donoghue, C. and Upton, V. 2014a. The role of subsidy payments in the uptake of forestry by the typical cattle farmer in Ireland from 1984 to 2012. *Irish Forestry* 71: 92-112.

Ryan, M., O'Donoghue, C. and Upton, V. 2014b. Land use change from agriculture to forestry: a structural model of the income and leisure choices of farmers. Paper presented at European Association of Agricultural Economists. Ljubljana, Slovenia. 25-28th August 2014. http://ageconsearch.umn.edu/record/182753

Ryan, M. 2016. Economics of farm afforestation. Unpublished Ph.D. thesis. Hardiman Library, National University of Ireland, Galway.

Teagasc. 2015. Preparing for Thinning. Available at https://www.teagasc.ie/media/website/publications/2015/Timber_Measurement_web.pdf [Accessed November 2017]

UN 2016. Sustainable Develeopment Goals. United Nations. Available at http://www.un.org/sustainabledevelopment/sustainable-development-goals/ [Accessed November 2017].

Xu, C., Holly Wang, H. and Shi, Q. 2012. Farmers' income and production responses to rural taxation reform in three regions in China. *Journal of Agricultural Economics* 63: 291-309.

Upton, V., Ryan, M., Farrelly, N., and O'Donoghue, C. 2013. The potential economic returns of converting agricultural land to forestry: an analysis of system and soil effects from 1955 to 2009. *Irish Forestry* 70: 61-68.

Zhong, Y., Ding, Y.B. and Zhao, S.J. 2012. Financial support for agriculture, taxation, inertia effect and the development of agricultural modernization. *Journal of South China Agricultural University (Social Science Edition):* 2.

Appendix

The distribution of National Farm Survey (NFS) soil codes by region is shown in Table 1. These codes reflect the potential range of uses or limitations, ranging between soil code 1 which is suitable for a wide range of agricultural uses and soil code 6 which is extrememly limited for agricultural use. Spatial patterns are evident particularly in relation to the extremes. Soil code 6 (poorest soils) areas are located primarily in the mid-west and west, while the greater proportion of soil code 1 occurs in the south, south east and midlands. These soil codes also approximate to forest yield classes for Sitka spruce with soil code 1 approximating to YC 24 and soil code 6 approximating to YC 14.

Table 1: *Distribution of soils by region according to data collected by the Teagasc National Farm Survey (2015).*

Region	**Soil code**					
	1	**2**	**3**	**4**	**5**	**6**
Louth, Leitrim, Sligo, Cavan, Donegal, Monaghan	5.2	22.4	29.9	28.0	20.2	0.0
Dublin	1.1	1.8	0.0	0.0	0.0	0.0
Kildare, Meath, Wicklow	9.6	22.7	15.7	4.4	4.3	0.0
Laois, Longford, Offaly, Westmeath	25.9	13.6	8.6	18.3	9.3	0.0
Clare, Limerick, Tipperary N.R.	7.6	2.1	14.5	4.2	4.1	49.6
Carlow, Kilkenny, Wexford, Tipperary S.R., Waterford	20.3	14.3	8.0	8.0	4.0	0.0
Cork, Kerry	27.9	2.2	3.8	18.1	36.6	14.1
Galway, Mayo, Roscommon	2.3	21.0	19.5	18.9	21.4	36.3
	100.0	100.0	100.0	100.0	100.0	100.0

Nursing effects of birch on Sitka spruce grown on an industrial cutaway peatland

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Abstract

The suitability of major conifer species for afforestation of industrial cutaway peatlands is limited to a narrow range of site types. There is some evidence that establishment of Sitka spruce (*Picea sitchensis*) or Norway spruce (*Picea abies*) with birch (*Betula* spp.), as a mixed stand or by under planting spruce in an established birch canopy, can improve the productivity of the conifer crop. Management of mixed Norway spruce and birch crops is now a well-established management model used in southern Sweden (Kronoberg approach). In this study, a mixed spruce-birch trial, established in 2000 under the previous BOGFOR programme, was re-evaluated to determine if there was any evidence of a nursing effect of birch on Sitka spruce. Analysis of various planting configurations showed that planting the two species at the same time in alternate rows produced the best results in terms of total basal area, top height, mean DBH and height of Sitka spruce. When compared to pure Sitka spruce stands, the productivity was c. 38% higher for trees planted at the same time in alternate rows with birch. Although the definitive physiological factors contributing to the nurse effect of birch on Sitka spruce are still unclear, these results and others suggest the nursing effect is probably due to enhanced foliage nutrition possibly associated with increased nutrient availability due to decomposition of birch litter or increased root aeration. There was no evidence of a reduction in exposure and frost stress in mixed species treatments. The implications of these findings are that the potential area suitable for Sitka spruce on cutaway industrial peatland sites can be expanded when planted in combination with birch. Moreover, the potential utilisation of birch thinnings for biomass and the final Sitka spruce crop for timber may be a particularly suitable option for Bord na Móna, since it may potentially fulfil both bioenergy and timber production objectives. Further research is, however, required to assess whether the nursing effect will continue and to evaluate the viability of the proposed silvicultural system on cutaway peats. The timing of silvicultural interventions is particularly important to ensure that a Sitka spruce crop in not suppressed whilst still preserving the birch nurse effect.

Keywords: *Birch, Sitka spruce, nurse species, cutaway peatlands.*

Introduction

The afforestation of suitable industrial cutaway peatlands in the Republic of Ireland

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could make a significant contribution to attaining the targets set out in the government's forest strategy. It is estimated that between 16,000 and 20,000 ha of the Bord na Móna (The Turf Development Board) cutaway peatland resource has afforestation potential (Renou-Wilson et al. 2008). In addition to potentially providing raw materials for the timber processing sector, there is now potential for wood energy production from Bord na Móna lands close to existing end-use facilities. These woodland products are also suitable for co-firing in the peat-burning power stations and would extend these stations' working life, as well as providing employment in the harvesting and transport of wood fuel.

Bord na Móna cutaway peatlands are extremely heterogeneous below ground even though the landscape may look deceptively uniform in appearance from above. The peat varies in type, depth (because of the undulating topography of the underlying bog floor and local harvesting practices), pH, nutrient status, moisture regime (drainage) and in the geomorphology of the underlying (pre-bog) relict soils. All of these factors influence the choice of species for future afforestation. Afforestation of Irish cutaway peatlands, from the 1960s onwards, was perceived to offer good potential (OCarroll 1962, 1966, Gallagher and Gillespie 1984). A large cutaway peatland afforestation programme (mostly with Sitka spruce (*Picea sitchensis* (Bong.) Carr.)) on the cutaways, initiated in the mid-1980s to 1990s, resulted in c. 40% of crops failing to produce a commercial crop. This was mostly due to poor site selection and general sensitivity of Sitka spruce to frost, compounded by two severe late spring frosts that occurred in 1989 and 1991 (Renou-Wilson et al. 2008). Current guidelines now favour the selection of Norway spruce (*Picea abies* (L.) Karst) as the commercial conifer species of choice on these sites (Horgan et al. 2004, Renou-Wilson et al. 2008), despite the lower yield potential, when compared to Sitka spruce. More recent studies conducted on Bord na Móna experimental trials planted between 1995 and 2000 suggest that Sitka spruce and Norway spruce may only be suitable on *Phragmites* or woody fen peat-dominated sites with a maximum peat depth of 0.8 m (Black et al. 2017a, 2017b - this issue). As a natural coloniser of cutaway peatlands, birch appears to tolerate deeper peats and less well drained sites (Renou-Wilson et al. 2008, Renou-Wilson et al. 2010, Black et al. 2017a, 2017b).

The positive effects ("nursing") of growing mixed species stands have been documented in many studies (Cannell et al. 1992, Renou-Wilson et al. 2009). Horgan et al. (2004) describe why mixtures work in an Irish context and list the benefits as nutritional, improved soil aeration, providing shelter from wind or protection from frost. It has also been suggested that birch may be a suitable nurse species for Norway spruce in Nordic countries (Fahlvik et al. 2011). Johansson (2003) reported a higher total mean annual increment in mixed stands of birch and Norway spruce (11.5 m^3 ha^{-1} $year^{-1}$) when compared with pure spruce stands (7.2 m^3 ha^{-1} $year^{-1}$). Management of naturally regenerating birch/spruce mixtures is now a well-established silvicultural system (Kronoberg system) in southern Sweden. The density of the nurse crop and the time of thinning have been found to be critical for Norway spruce growing on Finnish peat soils (Hilli et al. 2003). The Kronoberg system, or variations thereof, may be particularly attractive in the Bord na Móna context because there is potential to produce both biomass for energy from initial birch thinnings followed by a final harvest of spruce for commercial timber (Renou-Wilson et al. 2010).

Ideally, mixed forest stands should be comprised of a shade-tolerant, late-succession species in the lower stratum and an early succession species in the upper stratum (Assmann 1970). The natural relation between birch and Norway spruce in a mixed stand, therefore, seems to be a good ecological combination. Sitka spruce is, however, generally considered a light demander (Horgan et al. 2004, Kennedy et al. 2007) and should only be used in certain circumstances in mixture with birch. This has been shown in a demonstration area, established under the BOGFOR programme, where Sitka spruce initially grew extremely well under an established birch canopy but subsequently slowed considerably when the birch canopy was not opened up (Renou-Wilson et al. 2010). Birch in mixture with Sitka spruce, Norway spruce or western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) is a recommended mixture in Ireland (Horgan et al. 2004) but the authors stressed the importance of removing the birch overstorey to allow the conifers to develop as practiced in Finland (Hilli et al. 2003).

Mason (2006) describes two experiments, established in the late 1990s in the UK, to examine the response of both species in a birch/Sitka spruce mixture. Unlike the current cutaway trial, however, these UK trials examined sites where naturally regenerated birch had invaded sites already planted with spruce. Experiments were also set up in 2000 during the BOGFOR programme to investigate the potential nursing effect of naturally regenerated birch on planted Sitka spruce. Other trials included treatment plots of both species planted at the same time or Sitka spruce planted between rows of established downy birch (*Betula pubescens* Ehrh.) and pure plots of Sitka spruce after four growing seasons (Renou-Wilson et al. 2008). However, long-term assessments are required to assess the interaction between the two species over time. The long-term nursing potential of birch on Sitka spruce when planted in different configurations in relation to timing of planting and relative mixtures of the two species at planting were examined in this study.

The productivity benefit or loss to the target species (i.e. Sitka spruce in this case) in a mixed stand is a function of many interacting processes, such as different proportions of the species mixture (Mason 2006, Pretzsch 2009), resource availability, resource use efficiency, competition for stand space (packing density) and site type (for review see Assmann 1970, Pretzsch 2009). To evaluate the performance of the target species in mixed species planting configurations, some measure of the interaction between the two species is required, which is difficult to do based on once-off stand measurements. However, mixture proportions based on individual species' basal area or crown projection areas (Pretzsch 2009) and other competitive indices, such as crown competition factors, have been demonstrated to be useful to describe competition effects on tree growth (Wykoff 1990, Black 2016). It is hypothesised that the productivity of the target species (Sitka spruce) may increase or decrease under different species mixture configurations with birch depending on the availability, utilisation and competition of resources for tree growth by the two species and the extent of any protection one species may offer over the other (e.g. protection against frost). To test this hypothesis, assessments of the performance of Sitka spruce in a mixed species trial set up in 2000 under the BOGFOR programme was carried out. This study explores the use of traditional and new approaches for assessing the productivity benefit or loss due to species interaction, by extending concepts outlined by Pretzsch (2009). The other objectives of the study were to assess the potential of spruce/birch mixtures for the afforestation of industrial cutaway peatlands and to establish if any management interventions are required at the current stage of canopy development.

Materials and methods

Experiment KTY14/00

The experiment was established in 2000 in the Blackwater production area of Bord na Móna's industrial cutaway peatland area near the Shannonbridge ESB peat-fired power plant (geographic coordinates at centre of experiment in ITM WGS 84 projection is 53.2938° N and -7.9794° E). The experiment was set up in a randomised block design on bare milled peat (mostly *Phragmites*) with a peat depth of 1 to >2 m over a calcareous mud sediment. The experiment was set out in three blocks, with six randomised plot treatments in each block (Figure 1): Pure Sitka spruce planted in 2000 (SS); alternate rows of birch and Sitka spruce, planted at the same time in 2000 (SB); alternate rows of birch and Sitka spruce, with spruce planted 2 years after the birch in 2002 (SB_2); alternate rows of birch and Sitka spruce, with spruce planted 4 years after birch in 2004 (SB_4); one row of birch and two rows of Sitka spruce planted at the same time in 2000 (SSB); and one row of birch and three rows of Sitka spruce planted at the same time in 2000 (SSSB).

All plots (plot size of 45 × 45 m) were planted at a density of 2,500 trees per ha at a row spacing of 2 × 2 m, comprising of pure Sitka spruce (*Picea sitchensis* origin SQ UK Scot V12) or Sitka spruce mixed with common birch (*Betula pubescens,* origin BC UK106 ZP20), when the two species were planted at the same time. There is no clear documentation that the same provenance of Sitka spruce was used in the delayed planting after 2 and 4 years, but research practice at the time would have ensured that

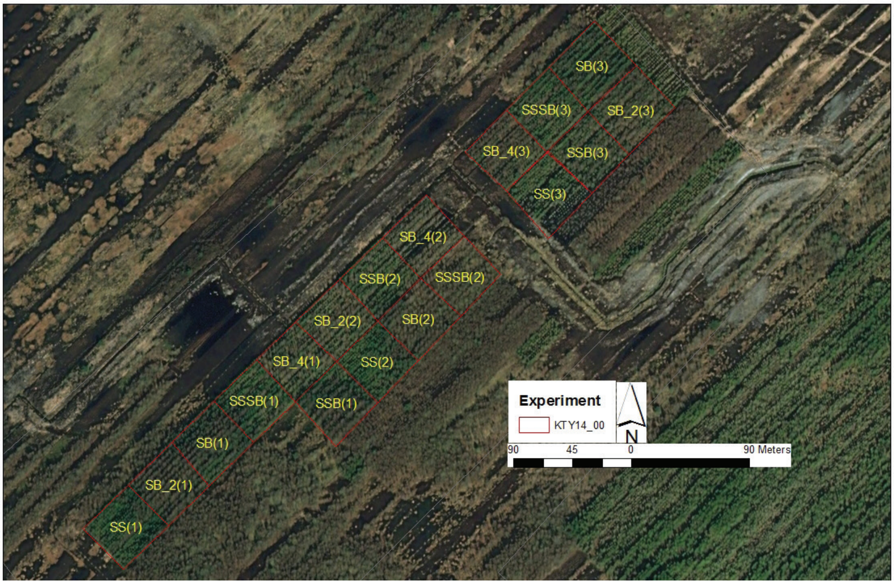

Figure 1: *The layout of experiment KTY14/00 established in 2000, showing treatments represented by letters and numbers (parenthesis) for the three replicated blocks. Treatments were as follows:*

- *SS = Sitka spruce planted in 2000;*
- *SB = alternate rows of Sitka spruce and birch, planted in 2000;*
- *SB_2 = alternate rows of birch and Sitka spruce, with spruce planted after 2 years in 2002;*
- *SB_4 = alternate rows of birch and Sitka spruce, with spruce planted after 4 years in 2004;*
- *SSB = two rows of Sitka spruce and one of birch planted in 2000;*
- *SSSB = three rows of Sitka spruce and one of birch planted in 2000.*

all provenances used were of QCI origin. All plants were sourced from the Coillte Ballintemple nursery in Co. Carlow. Sitka spruce was planted as bare-root stock (2+1, i.e. a 3-year-old transplanted seedling). Birch was planted as bare root stock (1U1, i.e. a 2-year-old undercut seedling).

At planting time (initial or under-crop), the plots (birch or Sitka spruce) were fertilised with rock phosphate applied in bands at a rate of 175 kg ha^{-1} (21 kg P ha^{-1}). All plots received a second broadcasted application (175 kg ha^{-1} of rock phosphate combined with 250 kg ha^{-1} of muriate of potash) after 2 years. The performance of both species in this trial was evaluated after four growing seasons, as part of the BOGFOR programme (Renou-Wilson et al. 2008), but there have been no management interventions on, or reassessments of this experiment since 2004.

Re-assessment of establishment data

The initial assessment data from the BOGFOR project was collected by the research forester, but the data and collection protocol were developed by one

(FRW) of the authors. However, there is no detailed record of the exact sample plot locations. The original experimental plot layout did not include buffer rows to account for edge effects. However, sample plots (10 × 20 m) were established in the centre of each replicated treatment plot to ensure that edge trees were not measured. A sample of c. 50 trees per plot were measured at the end of 2002, 2003 and 2004 to assess seedling height (in cm to 0.1 cm precision) and percentage survival following planting.

Plot surveys

Plot surveys using 0.03 ha (10 m radius) circular subplots were established in each plot after which diameter at breast height (1.3 m, DBH in cm), individual tree height (m), top height (mean height of largest DBH tree) were assessed. The stocking level of each species in the treatment subplots was determined in February 2017. These subplots were located near the centre of each plot to ensure that the sample plot area fell completely within the experimental plot and that edge trees were not measured.

The DBH of all trees was measured (to 0.1 cm precision) within a 10 m radius from the centre of the plot. Tree height (H) was also measured for trees representing the minimum, maximum, median, 25th and 75th percentile of the DBH distribution in the plot. Tree height measurements were taken using a Haglof Vertex IV ultrasonic device (Haglof, Sweden). All plot data were collected using the Field Map system (IFER, Czech Republic).

Height (H) values for unmeasured trees in the plot were then derived from measured DBH values using a DBH-H model for Sitka spruce and birch using the function (Pienaar and Turnbull 1973):

$$H = 1.3 + a(1 - Exp(b - DBH)^{(\frac{1}{c})} \quad [1]$$

where H is tree height, DBH is diameter and coefficients a, b and c were solved using non-linear curve least squares fitting procedures using R software. All coefficients and model fits were significant at $p < 0.05$. Additional statistical analysis of model residuals using the Shapiro-Wilk test was carried out to ensure all DBH_H model residuals were normally distributed.

Top height was estimated from the measured height of the maximum DBH tree within the sample plot. Site index (a productivity index) for Sitka spruce, which is a normalised top height at 30-years, was calculated using the GROWFOR model (Broad and Lynch 2006).

Quantifying the interactive effect of mixed species configurations

Mixture proportions of basal area for a species of interest (e.g. Sitka spruce, m_{sp} ($BA_{obs\ sp}$))

are a convenient way of determining the share of basal area under different species mixture planting configurations:

$$m_{sp}(BA_{obs}) = \frac{BA_{obs\ sp}}{BA_{obs\ sp} + BA_{obs\ b}} \quad [2]$$

where $BA_{obs\ sp}$ and $BA_{obs\ b}$ are the observed basal area (in m^2 ha^{-1}) of Sitka spruce (*sp*) and birch (*b*), respectively.

Pretzsch (2009) suggests that a better way of assessing species and site specific growing space requirement is to adjust the observed basal area proportions in a mixed stand by the basal area of a pure stand of each species grown on the site of interest. The relationship between the basal area of both species in a pure stand, which expresses the species-specific packing density, is applied to adjust observed basal areas of Sitka spruce and birch to their share of stand space and resources. Hence, the following adjusted mixture proportion equation was applied (Prezsch 2009):

$$m_{sp}(BA_{ref}) = \frac{BA_{obs\ sp}/BA_{ref\ sp}}{BA_{obs\ sp/BA_{ref\ sp}} + BA_{obs\ bi}/BA_{refb}} \quad [3]$$

where m_{sp} (BA_{ref}) is the adjusted mixture proportion for Sitka spruce and BA_{ref} is the observed basal area for pure spruce (*sp*) and birch (*b*) grown in the same site. The $BA_{ref\ sp}$ values were derived from the basal area of the pure Sitka spruce plots (i.e. the SS treatment). Since there was no pure birch treatment in the experiment, $BA_{ref\ b}$ was approximated based on the mean basal area of birch in the mixtures and the relative proportion of initial species stem numbers in the different treatments within each experimental block (*i*):

$$BA_{ref\ b} = \frac{(BA_{b\ \mathrm{SB}\ (i)} \times 2) + \left(BA_{b\ \mathrm{SSB}\ (i)} \times \frac{3}{1}\right) + \left(BA_{b\ \mathrm{SSSB}\ (i)} \times \frac{4}{1}\right) + (BA_{b\ \mathrm{SB}_2(i)} \times 2) + (BA_{b\ \mathrm{SB}_4(i)} \times 2)}{5} \quad [4]$$

where BA_b is the basal area of birch in the SB, SSB, SSSB, SB_2, and SB_4 treatments within each block *(i)*. It is assumed that $\mathrm{BA}_{\mathrm{ref\ b}}$ derived from equation 4 would be the same as the basal area of pure birch grown in the same experimental block. It is possible that spruce may influence the basal area of birch in mixtures or that the actual basal area of pure birch, if grown in the same experimental block, may be lower due to competition between trees within the crown. However, since comparisons of m_{sp} (BA_{ref}) are made across the different treatments this should not introduce any bias because m_{sp} (BA_{ref}) is a ratio and $BA_{ref\ b}$ is constant for each block.

The adjusted mixture proportion (m_{sp} (BA_{ref})) is a measure of potential basal area production, relative to pure stands of spruce and birch grown at the same site. The authors propose that the ratio of m_{sp} $(\mathrm{BA}_{\mathrm{obs\ sp}})$ over m_{sp} (BA_{ref}) would provide an indication of the interaction between resource utilisation or resource availability by spruce and competition for the share in stand space by the two species in a mixed stand. This is because the difference between the observed and adjusted basal area mixture proportions is a measure of the difference in the realised basal area production of spruce compared with the potential basal area production of spruce in a given treatment. Therefore, m_{sp} ($BA_{obs\ sp}$) must be less than m_{sp} (BA_{ref}), which is true given the formulation of Eqs. 2 and 3. In other words, the potential basal area productivity is always greater than the observed basal area production. Hence, a higher (m_{sp} (BA_{obs})/m_{sp} (BA_{ref}) ratio would indicate that a higher proportion of potential productivity is realised because site resource utilisation is maximised and/or competition effects are minimised.

Crown competition factor (CCF) is an alternative way of assessing competition within the crown. Open-grown crown radius was derived using equations presented by Hasenauer (1997):

$$cw = e^{a} DBH^{b} \qquad [5]$$

where *cw* is the open-grown crown radius (in m) and DBH is diameter at breast height (cm). There were no data available specific to the study region to derive *cw* estimates for Sitka spruce and birch. For Sitka spruce, the coefficients *a* and *b* for Norway spruce were taken directly from Hasenauer (1997); coefficients for birch were based on corresponding estimates for other broadleaves (Hasenauer 1997). These equations provide estimates of crown width of open-grown trees of each species. *CCF* (expressed as a percentage) for each treatment plot was then derived using equation defined by Wykoff (1990):

$$\mathrm{CCF} = \frac{1}{Area} \times \sum (\mathrm{OGCA}) \times 100 \qquad [6]$$

where *Area* is the area of the sample plot (0.03 ha) and OGCA is the sum of open-growth crown areas for all trees in the plot, expressed as m^2 per unit of sample plot area. CCF is a relative measure of packing density in the crown space and values above 200% indicate that tree growth may be limited by light availability due to crowding of the canopy (Black 2016, Preztsch 2009).

Foliar analysis

Foliage samples were collected in February 2017 from Sitka spruce only to assess if any nursing effects were reflected in the nutritional status of needles. Foliage samples (4-5 tree bulked samples per replicated treatment) were collected from the top section of the canopy of 4-5 trees directly adjacent to the centre of each sample plot. The 18 bulked samples were dispatched immediately after collection to the Forestry Commission Research Laboratory Alice Holt, Farnham, Surrey, England. The following macro elements and trace elements were determined in each sample: nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), copper (Cu) and iron (Fe). Foliar samples were dried at 70 °C prior to weighing to remove any residual moisture content. The combustion method for determination of N was done using a Carlo Erba CN analyser (Flash1112 series) using 10 mg dried and ground needle samples. For P, K and trace elements, c. 100 mg of dried sample were weighed into a 15-ml borosilicate (or quartz) tube. One ml of concentrated sulphuric acid was added to each sample with 0.8 ml of hydrogen peroxide (30%). The tubes were then incubated on a heating block at 335 °C for 30 min or until the digests were clear. The samples were made up to 15 ml with distilled water and then analyzed on a dual view ICP-OES (Thermo ICap 6500).

Statistical analysis

ANOVA was performed, using the General Linear Models procedure in R (v3.4.1) to evaluate (fixed) effects of treatments (α), with sites as blocks (random effects, β) according to the following model:

$$Y_{ij} = \mu + \alpha_i + \beta_j + \epsilon_{ij} \quad [7]$$

where Y_{ij} is the dependent variable (stem number, basal area, DBH etc.), μ is the grand mean, α is the fixed effect of treatment, β the random effect of site, ϵ the residuals for treatment i and block j.

Numerous post hoc tests were carried out to ensure that the key assumptions underlying the random block ANOVA procedure were not violated. The model residuals were studied and in a few cases, the assumption of constant variance was violated according to the Shapiro-Wilk statistical test (in R v3.4.1). In these cases, the data were logarithmically or arcsine transformed before ANOVA, which improved the distribution of the residuals sufficiently to meet ANOVA requirements. A final test was carried out to ensure that there was no interaction between the block and treatment using Tukey's test for additivity from the "asbio" library in R. The null hypothesis is that there is no interaction term.

Means effects were tested separately for each species or aggregated plot level estimates, where there was a significant treatment effect (see Figure 2) and if all post-hoc test results confirmed basic ANOVA assumptions were not violated.

Finally, once all conditions of the random block AVOVA were met, differences between mean values for treatments was determined using Tukey's HSD test in R. For all statistical tests, p values ≤0.05 were considered to be significant.

Results

Post establishment assessments

Analysis of variance on the early establishment data revealed that there was no significant block or treatment effect for seedling height or survival rates in 2001 and

2003 (data not shown). In 2004, the mean height of Sitka spruce was significantly lower in the SSB_2 and SSB_4 treatment, when compared to treatments where Sitka spruce was planted 2 to 4 years earlier, as expected (Figure 2A). Although survival in the pure Sitka spruce treatment (SS) and the alternate rows of Sitka and birch planted at the same time (SB) was marginally lower when compared to the other treatments, this was not significant (Figure 2B).

There was no detailed documentation of the impact of frost in different plot treatments except for the May 2004 assessment carried out after a frost event. However, no treatment-specific differences in the extent of frost damage were observed. The only available record in the research notes indicated that the research forester observed that frost damage was more evident in plots located in the mid-south eastern areas of the site (i.e. plots SSB(1), SSSB(2), SS(2) and SB(2), see Figure 1).

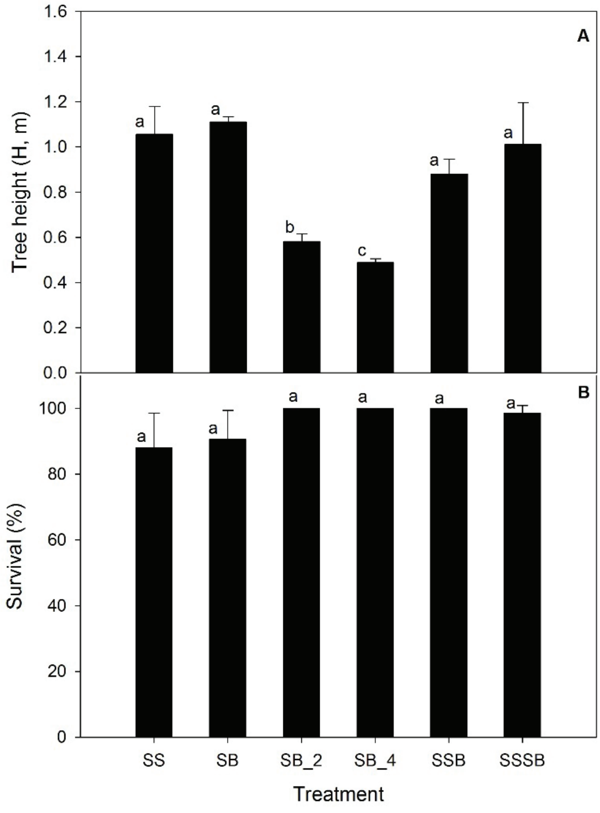

Figure 2: *Mean height (A) and survival (B) of Sitka spruce across the different planting treatments (see Figure 1 for code descriptions). Histograms (vertical bars indicate standard deviation) with different letters indicate that adjusted mean values are significantly different (at P <0.05).*

Crop performance after 16 growing seasons

The growth of Sitka spruce in the pure stand treatment (SS, no birch) was stunted, showing the characteristic P and K deficiency symptoms, based on visual observations. In contrast, the Sitka spruce trees in the mixed species plots planted at the same time as the birch showed no signs of a decrease in growth, no visual needle deficiency symptoms or signs of suppression by birch at this stage of canopy development.

The random block ANOVA model was significant for both DBH and height of Sitka spruce between the treatment and blocks (Table 1). Site index was only significant for the treatment effects (Table 1). Tukey's additive post hoc tests revealed that there was no interaction between treatments and block (p = >0.05).

Species was not included in the model as a factor, so mean comparisons are only valid within species (Figures 3, 4 and 5) and for total plot data (Figure 5).

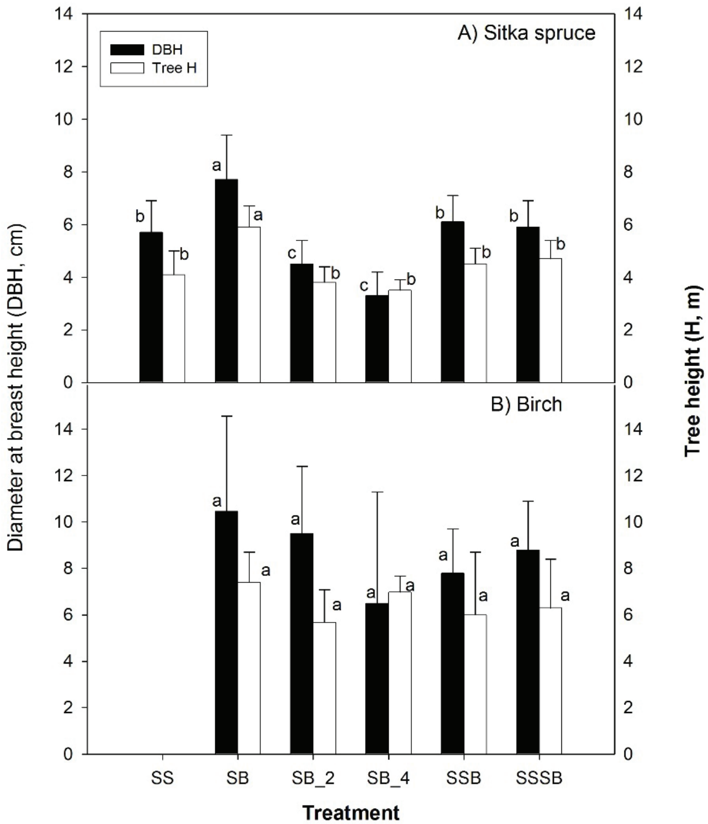

Figure 3: *Mean (plus one standard deviation) DBH and height values for Sitka spruce (top panel A) and birch (panel B) across the different planting treatments (see Figure 1 for code descriptions). Histograms with different letters indicate that mean values are significantly different (at P <0.05).*

Table 1: *Results from the random block ANOVA model showing the significance of the treatment (degrees of freedom = 5) and block effects (degrees of freedom = 2) on plot variables, such as DBH, and mean tree height area for Sitka spruce. All post hoc tests for normality of model residuals and treatment - block interactions were not significant (p >0.05).*

Source of Variation	SS	df	MS	F-value	p-value
DBH (cm)					
Blocks	10.4	2	2.2	4.2	0.011
Treatments	49.7	5	8.5	6.4	0.026
Error	14.2	11	1.6		
Height (m)					
Blocks	3.14	2	2.5	3.6	0.03
Treatments	76.4	5	6.1	6.1	0.021
Error	31.5	11	1.9		
Site index (m)					
Blocks	1.54	2	1.54	0.57	0.463
Treatments	62.35	5	12.47	4.66	0.015
Error	29.47	11	2.67		

The mean comparison test results indicated that Sitka spruce, planted at the same time in alternate rows with birch, had a significantly greater mean DBH (from 19 to 57%) and height (from 20 to 47%), compared to those from the other treatment plots (Figure 3). When compared to the pure Sitka spruce treatment (SS), the DBH and height of Sitka spruce was c. 35% higher in the plots planted in alternate rows with birch (SB, Figure 3).

Although the height and diameter of birch trees appeared to be higher than that of Sitka spruce, there was more variation in DBH and height of birch trees, when

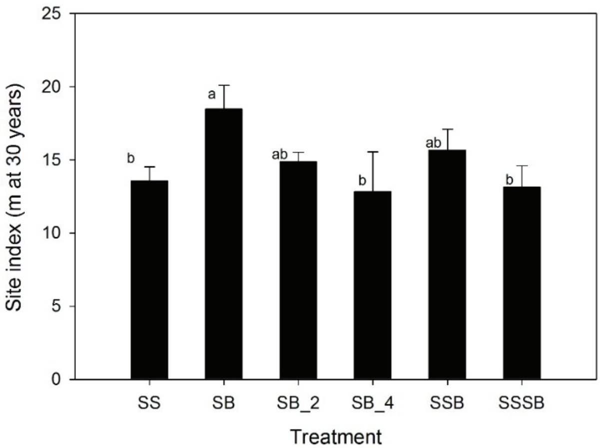

Figure 4: *Mean (vertical bars indicate one standard deviation) site index values for Sitka spruce across different treatments (see Figure 1 for code descriptions). Histograms with different letters indicate that mean values are significantly different (at P <0.05). Note: A site of index 10 and 15 is approximately equivalent to a potential yield class of 8 and 14 m^3 ha^{-1} yr^{-1}, respectively.*

compared to Sitka spruce (Figure 3). There was a significant block effect for DBH and mean plot height of birch trees (data not shown), but there was no significant treatment effect for either of the variables (Figure 3).

Site index trends provide some evidence that the productivity of Sitka spruce planted in alternate rows at the same time (SB) is enhanced when compared to the monoculture (SS) plots. It is also evident that planting Sitka spruce at higher densities than a 50:50 mix with birch (SSB or SSSB) or delayed planting of Sitka spruce under birch (SB_2, SB_4) appeared to offer no significant nurse effect, when compared to pure Sitka spruce treatments (SS, Figure 4).

Stocking density (stems per ha) of Sitka spruce and birch differed between the treatments as expected, but there was no significant difference in total stems per ha across all treatments (data not shown). The mean basal area of Sitka spruce in the monoculture treatment (SS) plots was not significantly different to the spruce/birch mixture treatment, SB (Figure 5A), even though the number of stems per ha was double that present in the SS treatment plots. The mean total basal area for treatment SB (alternate rows of Sitka spruce and birch planted at the same time) was significantly higher (22 to 59%), when compared to all of the other treatments (Table 5B). This was associated with the significantly higher diameters in Sitka spruce in the mixed species treatment (SB, Figure 3).

Nursing/competition interactions

To establish if different planting combinations resulted in the enhancement of productivity or potential suppression of Sitka spruce, two competition indices were investigated (Figure 5C and D). Evaluation of crown competition factors showed that growth may be light limited in the treatments where Sitka spruce was planted in alternate rows with birch (i.e. SB, SB_2, and SB_4) because CCF values are above the threshold value of 200% (Figure 5C). It is also evident that birch is dominating the crown in all mixed species treatments since the birch trees were generally 20-40% taller than Sitka spruce (Figure 3) and basal area mixture ratios for spruce ($m_{sp}(BA_{obs})$) in all mixed treatments were below 0.5 (range 0.16 to 0.45, data not shown). Differences in the ratio of observed and adjusted mixture proportions ($m_{sp}(BA_{obs}/BA_{ref})$) may indicate that basal area production in spruce is affected by a combination of factors, such as resource utilisation by spruce and/or competition for light/space by both species in a mixed stand (see Material and methods section). The calculated $m_{sp}(BA_{obs}/BA_{ref})$ value for the spruce/birch treatment SB was significantly higher by 20 to 62%, when compared to all other mixed species planting configurations (Figure 5D). These trends are broadly consistent with the observed variation in site index across the different mixed species treatments. Regression analysis of the relationship between site index and $m_{sp}(BA_{obs}/BA_{ref})$ confirmed a significant R^2 of 0.46 at $p < 0.05$ (data not shown).

It should be stressed that interpretation of differences between the delayed Sitka

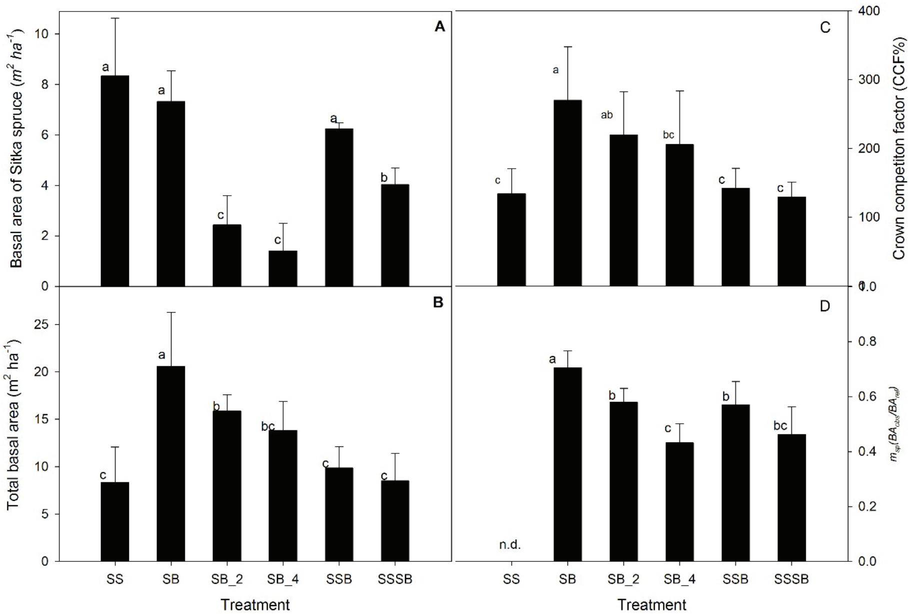

Figure 5: *Mean (vertical bars indicate one standard deviation) basal area (panel A), total basal area (panel B), crown competition factors (CCF, panel C) and the ratio of observed and adjusted mixture proportions ($m_{sp}(BA_{obs}/BA_{ref})$, panel D) for Sitka spruce across the different treatments (see Figure 1 for code descriptions). Histograms with different letters indicate that mean values were significantly different (at P <0.05).*

spruce planting treatments (SB_2 and SB_4) and the treatments planted in 2000 should be treated with caution, since differences in most cases (except for site index, Figure 4) may be associated with the differences in tree age. However, since there was a significantly lower $m_{sp}(BA_{obs}/BA_{ref})$ ratio in the SB_4, compared to other treatments, this may indicate poor resource utilisation efficiency or competition by birch in the canopy (Figure 5C and D). This would be consistent with the lowest site index value for the SB_4, compared to the other treatments.

Effect of mixture treatments on nutrient status of Sitka spruce

The nutrient status of Sitka spruce was investigated to assess if the apparent nursing effect by birch was related to nutritional factors. The mean foliage concentration of macronutrients and trace elements of Sitka spruce needles confirmed a significant treatment (p <0.05) effect for P and iron (Fe). Comparison of plot means shows that levels of P in needles of Sitka spruce sampled from the alternate birch/spruce row treatment (planted at the same time, SB) was c. 33% higher than levels from the all the other treatments. This observation is consistent with the significantly higher productivity of Sitka spruce in the SB, compared to the other treatments (Figure 4). There was no significant treatment effect for all other trace elements and macronutrients (Table 2 and data not shown).

Based on the macronutrient concentrations in needles, both N and P levels in Sitka spruce in all of the treatments are deficient. Threshold N and P values were considered to be 1.2 and 0.13%, respectively (from Renou-Wilson et al. 2008).

Discussion

The results show that, on this cutaway peatland site, Sitka spruce planted with birch in alternate rows at the same time had an improved growth performance (c. 35% for both DBH and height and a 38% increase in site index) compared to pure Sitka spruce stands (Figures 3 and 4). These findings are consistent with the results of other studies conducted in naturally regenerating birch and Norway spruce stands in Sweden (Fahlvik et al. 2011, Johansson 2003), which suggested that productivity of Norway spruce was improved when grown with birch. Other studies on the effect of the birch shelter on planted Norway spruce seedlings suggest that a reduction in the risk of frost damage largely explains the nursing effect (Langvall and Ottosson Löfvenius 2002, Klang and Eko 1999). Although there was no evidence of protection against frost damage to Sitka spruce in this study (Figure 2), the results provide supporting evidence that the nutritional status of Sitka spruce is improved when planted in alternate lines at the same time as birch (Figure 4 and Table 2). It is, as yet, unknown how long this nutritional effect will last in these crops. The results presented in this study are for an experiment which was planted in 2000, so the crop is only 16-years-old. Mason (2006) suggested that Sitka, because of its greater vigour than Norway spruce, will dominate birch after 30 years, even when the birch has been established in advance of the spruce. Clearly the interaction between birch and spruce in these mixed stands would depend on site type and climatic factors. In some cases, spruce may dominate the canopy (Mason 2006). However, in less fertile sites and sites prone to frost damage, such as the stands presented in this study, birch is likely to dominate the canopy (Figures 3 and 5C). Encroachment of birch in afforested sites planted with

Table 2: *Mean values of selected micro- and macro- nutrients in Sitka spruce needles sampled from different treatments. Mean values (standard deviation in parenthesis) with different letters indicate that mean values are significantly different (at P <0.05).*

Treatment	**N** (%)	**P** (%)	**K** (%)	**Fe** (ppm)
SS) Pure SS	1.10 (0.16)a	0.06 (0.01)b	0.60 (0.09)a	25.7 (2.4)b
SB) Alternate rows SS and BI	1.11 (0.29)a	0.09 (0.01)a	0.78 (0.07)a	32.2 (4.2)a
SB_2) Alternate rows, SS after 2 yrs	1.12 (0.12)a	0.07 (0.005)b	0.63 (0.18)a	26.9 (5.3)ab
SB_4) Alternate rows, SS after 4 yrs	1.1 (0.09)a	0.05 (0.02)b	0.64 (0.07)a	23.5 (5.3)b
SSB) 1 row BI 2 rows SS	1.2 (0.09)a	0.06 (0.01)b	0.58 (0.18)a	26.5 (4.9)ab
SSSB) 1 row BI 3 rows SS	1.01 (0.1)a	0.06 (0.01)b	0.69 (0.13)a	23.2 (3.6)b

spruce in the mid-1980s to early 1990s and second-rotation spruce stands is very common in the midlands (Black et al. 2017a, Renou-Wilson et al. 2008).

The results from this study indicate that the proportion of species in mixed stands influences the interaction between the two species. Treatments planted with a higher proportion of Sitka spruce than 50% and where planting of spruce in alternative lines took place after 2 to 4 years did not show any increase in productivity, when compared to pure spruce treatments (Figure 4). The higher site index, $m_{sp}(BA_{obs}/BA_{ref})$ ratio and levels of foliar P in the treatments planted in alternative rows at the same time (SB, Figures 4 and 5D, Table 2) may suggest that birch may provide additional nutrient resources as a result of recycling of P in the litter layer, which is then made available to Sitka spruce, thus enhancing resource utilisation. Although it is possible that crown competition by birch has not suppressed basal area production of spruce at this stage, CCF values above 200% indicate that crown competition will supress the future growth of spruce unless some of the birch is removed.

One of the limiting factors in the design of these experiments was that that a pure birch treatment was not included in the random block design. This would be important in the design of mixed species experiments so that meaningful interactive effects between the two species could be evaluated. Although an alternative method was devised to estimate the adjusted mixture proportions described by Preztsch (2009, see Eq. 4), this estimation required the formulations of some assumptions, which in certain cases may not be realistic. The delay of planting Sitka spruce also created a statistical design problem, because apparent differences between these treatments (i.e. SB_2 and SB_4) and others may simply be an age difference effect. A complex experimental design, possibly including split plots or many more treatments may be required to address the age-effect problem. The only case where a feasible comparison could be made was when the site index was compared (Figure 4), since this is age independent. In contrast, the use of the conventional yield class assessment of productivity may introduce additional error associated with tree age (Broad and Lynch 2006). It is also important that these issues are carefully considered in advance of any planned thinning intervention in these experiments. The authors would advocate the use of split plots (i.e. no treatment and a silvicultural treatment) within the current randomised block design and the use of CCF values as a guide to crown thinning if more work is to be done on this experiment in the future.

Johansson (2003) highlighted the potential use of birch/spruce mixtures for both biomass and timber production using the Kronoberg management approach, where birch is utilised for biomass from thinnings and the final Norway spruce crop produces valuable timber. Management of the mixed spruce/birch stands, such as the SB treatment stand presented in this study, using the Kronoberg type of approach may be particularly suitable to the Bord na Móna estate since it can fulfil both bioenergy and timber production objectives. In addition, since this nursing effect of birch on spruce is evident on deeper peat sites (>1 m), this means that the range of sites suitable for commercial timber production of spruce can be increased. Recent studies on Sitka spruce across a range of peat depths on Irish cutaway peatlands suggest that pure Sitka spruce may not be suitable on peat depths greater than 0.8 m (Black et al. 2017b - this issue). The results presented in this paper suggest that the peat depths suitable for Sitka spruce can be increased to a maximum of 2 m deep, if spruce is planted in a mixture with birch at the same time. However, further research is required to assess whether the nursing effect will persist over time, so the trial needs to be re-evaluated in the future to determine the viability of the proposed spruce/birch mixed stands with some adapted version of Kronoberg silvicultural system on cutaway peats in Ireland. Although the current study suggests that increased availability of P may be the primary factor contributing to the nursing effect of birch on Sitka spruce on cutaway peatlands, foliar level of both N and P are below the deficit threshold.

The timing of silvicultural intervention is particularly important to ensure that the Sitka spruce crop in not suppressed whilst still preserving the birch nurse effect. Evidence from this study suggests that the current mixed stands (i.e. treatment SB, SB_2 and SB_4) require some thinning intervention to remove the dominating birch crown (Figure 5C). Late silvicultural intervention would also increase the risk of whipping damage (crown and leader damage) to spruce by birch (Fahlvik et al. 2011, Hilli et al. 2003).

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References

Assmann, E. 1970. *The principles of forest yield study.* Pergamon Press, Oxford, p. 506.

Black, K. 2016. Description, calibration and validation of the CARBWARE single tree-based stand simulator. *Forestry* 86: 55-68.

Black, K., Mc Nally, G., Carey, M. and Keane, M. 2017a. *Assessment and Update of Species and Related Trials on Industrial Cutaway Peatlands with a View to Afforestation*. COFORD, Dublin.

Black, K., Keane, M., McNally, G. and Carey, M. 2017b. Effects of peat depth and aeration on species performance in afforested industrial cutaway peatlands. *Irish Forestry* 74: 23-39.

Broad, L. and Lynch, T. 2006. Growth models for Sitka spruce in Ireland. *Irish Forestry* 63: 53-79.

Cannell, M.G.R., Malcolm, D.C. and Robertson, P.A. (Eds.). 1992. *The Ecology of Mixed-Species Stands of Trees*. Blackwell, London.

Fahlvik, N., Agestam, E., Eko, P.M. and Linden, M. 2011. Development of single storied mixtures of Norway spruce and birch in Southern Sweden. *Scandinavian Journal of Forest Research* 26: 36-45.

Gallagher, G. and Gillespie, J. 1984. *The economics of peatland afforestation. 7th International Peat Congress*. Dublin, International Peat Congress, pp. 271-285.

Hasenauer, H. 1997. Dimensional relationships of open-grown trees in Austria. *Forest Ecology and Management* 96: 197-206.

Hilli, A., Päätalo, M.-L., Moilanen, M., Piiroinen, M.-L., Issakeinen, J. and Tillman-Sutela, E. 2003. The effect of nurse crop density and fertilization on the height and growth of Norway spruce seedlings on drained peatland. *Suo* 54(2): 69-79.

Horgan, T., Keane, M., McCarthy, R., Lally, M. and Thompson, D. 2004. *A Guide to Forest Tree Species Selection and Silviculture in Ireland*. O'Carroll, J.L. (Ed.). COFORD, Dublin.

Hynynen, J., Niemisto, P., Vihera-Aarnio, A., Brunner, A., Hein, S. and Velling, P. 2010. Silviculture of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) in northern Europe. *Forestry* 83: 103-119.

Johansson, T. 2003. Mixed stands in Nordic countries - a challenge for the future. *Biomass and Bioenergy* 24: 365-372.

Kennedy, S., Black, K.G., O'Reilly, C. and Ní Dhubháin, Á. 2007. The impact of shade on morphology, growth and biomass allocation in *Picea sitchensis*, *Larix × eurolepis* and *Thuja plicata. New Forests* 33: 139-153.

Klang, F. and Eko, P.M. 1999. Tree properties and yield of *Picea abies* planted in shelterwoods. *Scandinavian Journal of Forest Research* 14: 262-269.

Langvall, O. and Ottosson Löfvenius, M. 2002. Effect of shelterwood density on nocturnal near-ground temperature, frost injury risk and budburst date of Norway spruce. *Forest Ecology and Management* 168: 149-161.

Mason, B. 2006. *Managing Mixed Stands of Conifers and Broadleaves in Upland Forests in Britain*. Forestry Commission Information Note. Edinburgh, Scotland.

OCarroll, N. 1962. The progress of peatland afforestation in the Republic of Ireland. *Irish Forestry* 19: 93-101.

OCarroll, N. 1966. Growth check in Norway spruce and Scots pine due to potassium deficiency. *Irish Forestry* 23: 36-41.

Pienaar, L.V. and Turnbull, K.J. 1973. The Chapman-Richards generalization of von Bertalanffy's growth model for basal area growth and yield in even-aged stands. *Forest Science* 19: 2-22.

Pretzsch, H. 2009. *Forest Dynamics, Growth and Yield*. Springer-Velag, Heidelberg, p. 664.

Renou-Wilson, F., Keane, M., McNally, G., O'Sullivan, J. and Farrell, E.P. 2008. *Developing a Forest Resource on Industrial Cutaway Peatland*: *The BOGFOR programme*. COFORD, Dublin, p. 176.

Renou-Wilson, F., Keane, M. and Farrell, E.P. 2009. Afforestation of industrial cutaway peatlands in the Irish midlands: site selection and species performance. *Irish Forestry* 66: 85-100.

Renou-Wilson, F., Pollanen, M., Byrne, K. A., Wilson, D. and Farrell, E.P. 2010. The potential of birch afforestation as an after-use option for industrial cutaway peatlands. *Suo* 61: 59-76.

Wykoff, W.R. 1990. A basal area increment model for individual conifers in the northern Rocky Mountains. *Forest Science* 36: 1077-1104.

The potential of alternative conifers to replace larch species in Ireland, in response to the threat of *Phytophthora ramorum*

Richard Walsh[ab*], Andrew Cameron[b], Scott McG. Wilson[c] and Niall Farrelly[a]

Abstract

Forest ecosystems are facing many challenges in the wake of recent pest and disease outbreaks, coupled with uncertain future climate conditions. A particular challenge emerges from the recent outbreak of *Phytophthora ramorum* identified in Japanese larch (*Larix kaempferi*) in 2010. Its subsequent spread has caused widespread damage to Japanese larch stands and has resulted in the Japanese, European (*Larix decidua*) and hybrid (*Larix* × *eurolepis*) larches no longer being grant-aided in the Irish afforestation programme in Ireland. Over 20% of forest stands contain some quantity of larch, with a total area of 32,057 ha. Japanese larch is the predominant species with 27,859 ha, 86% occurring as mixed stands and 79% in mixture with Sitka spruce (*Picea sitchensis*). The objective of the study was to examine the range of alternative conifer species that may be suitable to replace larch which potentially have similar or higher levels of productivity, acceptable timber properties, while affording reduced levels of risk from pest/disease outbreak. To assess productivity, yield class of a range of species in mixture with larch across a gradient of soil types was assessed. Analysis of this data indicated that Sitka spruce, western red cedar (*Thuja plicata*), grand fir (*Abies grandis*), western hemlock (*Tsuga heterophylla*), Norway spruce (*Picea abies*), European silver fir (*Abies alba*), noble fir (*Abies procera*) and Douglas fir (*Pseudotsuga menziesii*) provide suitable alternatives, showing higher levels of productivity across a range of soil types. A strong positive correlation was found between the yield classes of (a) Japanese larch and western hemlock ($r = 0.70$), (b) hybrid larch and Douglas fir ($r = 0.73$) and (c) European larch and Sitka spruce ($r = 0.61$) growing on the same sites. Regression equations were developed between the site yields of Japanese, European and hybrid larches and those of alternative species, as a useful tool to predict growth performance of potential alternative species across a range of soil types where larch is currently growing. The predictive power varied for different species pairings (r^2 of 0.24 to 0.87) with the strongest relationships between the yields of Japanese larch and Norway spruce on basin peat ($r^2 = 0.71$) and Japanese larch and Douglas fir on podzol soils ($r^2 = 0.76$; $y = 1.2632x + 2.6316$). Given the significance of Sitka spruce/Japanese larch mixtures in Irish forestry, future research should focus on the potential for mixtures combining Sitka spruce and alternative

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Pacific conifers (e.g. Douglas fir, grand fir, western hemlock and western red cedar) that may enhance the resilience of and maintain productivity.

Keywords: *Larch,* Phytophthora ramorum*, pests and diseases, alternative conifers, silvicultural mixtures, forest yield.*

Introduction

Over the past decade, there has been a rise in the number of damaging invasive biotic agents detected in European (Jones and Baker 2007, Brasier 2008) and Irish forests (McCracken 2013, O'Hanlon et al. 2016a). Some of the potential contributing factors leading to this increase include disturbances to forest ecosystems by humans, changing climatic conditions, increases in international trade (Stenlid et al. 2011) and international travel by humans (Hulme 2009), with the spread of pathogens possibly having been facilitated by transportation of infected plant material to new areas (Levine and D'Antonio 2003). More recently, climate change has potentially reduced the abiotic constraints that formerly prevented the geographical spread of damaging pathogens (Pautasso et al. 2010). The rise in biotic risk has consequentially reduced the range of tree species available for afforestation and reforestation, with foresters increasingly dependent on a few species for establishment of commercial plantations (Read et al. 2009).

The recent outbreaks of *Phytophthora ramorum* (Werres, De Cock & Man in't Veld) in *Larix* spp. and ash dieback disease (*Hymenoscyphus fraxineus*) in *Fraxinus* spp. in Ireland have highlighted the risks to our forest resources from pathogenic attacks, and both diseases have caused considerable damage to forests in Ireland and Britain (Brasier and Webber 2010, Webber et al. 2010). The fungal pathogen *Phytophthora ramorum* was first detected in Ireland on *Rhododendron* spp. (EPPO 2003, O'Hanlon et al. 2016b) and was subsequently detected on Japanese larch (*Larix kaempferi* (Lamb.) Carr.) in 2010 (EPPO 2010). This multi-lineage oomycete pathogen (O'Hanlon et al. 2017) has now been detected on 30 hosts in Ireland, among which the coniferous genera include *Abies*, *Larix* and *Picea* (O'Hanlon et al. 2016b). Larches (including Japanese, hybrid (*Larix* × *eurolepis* A. Henry) and European (*Larix decidua* Mill.) larch) appear to display the least resistance. It is an aggressive and unpredictable pathogen and is a serious threat to Irish forestry (O'Hanlon et al. 2014).

More recently, red band needle blight (*Dothistroma septosporum* Dorog.) has been detected in young Scots pine (*Pinus sylvestris* L.) growing in Ireland (Cathal Ryan, Forest Service, pers. comm.). This disease has previously caused widespread dieback and mortality in other *Pinus* species including Corsican pine (*Pinus nigra* subsp. *laricio* Maire) in England and Wales, and lodgepole pine (*Pinus contorta* Douglas ex Loudon) in Scotland (Cameron 2015). The lesser known *Phytophthora lateralis* has been reported causing death in Lawson cypress (*Chamaecyparis lawsoniana* (A.Murray bis) Parl.) in Ireland (O'Hanlon et al. 2016a) and also has infected this species and, occasionally, western red cedar (*Thuja plicata* Donn ex D.Don) in Britain (Green and Webber 2015).

Larch species are among the more important commercial conifer tree species in Irish forestry. The extensive use of larch in Irish forests is explained by the relative ease of plantation establishment, satisfactory productivity and durable, versatile timber, marketable in Britain and Ireland. Larch also provides an important role in biodiversity, permitting the retention of ground vegetation below the canopy, enhancing the support of macrofungi on the forest floor (Heslin et al. 1992), enhancing recreational amenity and improving the visual appeal of forest landscapes through the contrast of colour in winter foliage. These species have found favour in mixed species stands where they are commonly used as the second or third species, occupying a minority of the canopy. They were used extensively in the afforestation programme in Ireland up to 2010, typically in mixture with Sitka spruce (*Picea sitchensis* (Bong.) Carr.) at a rate of 80% spruce to 20% larch, often utilised in Ireland and Britain to provide a level of species diversity in Sitka spruce stands (Mason 2014). *P. ramorum* poses a significant threat to the standing resource of larch and is likely to have economic implications for a range of end-use markets, including those for fencing and exterior cladding (Brasier and Webber 2010). The extensive damage to larch caused by *P. ramorum* in both Ireland and Britain indicates the potential for invasive damaging pathogens to undermine future forest plantations, including a reduction in the range of tree species available for commercial use. While the current afforestation programme in Ireland lists a range of coniferous and broadleaved species that remain eligible for grant aid, species choice is becoming more restricted with the withdrawal of larch, ash (*Fraxinus excelsior* L.) and Lawson cypress from the permitted list of species (DAFM 2016). As a result of this reduction in species choice and the need to replace stands of diseased larch trees, an initial review was undertaken to explore the potential of alternative conifer species that have potentially similar or increased levels of productivity, acceptable timber properties, while affording reduced levels of biotic risk. Therefore, the objective of the study was to examine the range of alternative conifer species that may be suitable to replace larch in both restocking and new afforestation schemes.

Materials and methods

An estimate of the area of larch in Ireland that may be susceptible to disease threat was obtained through an examination of inventory databases for privately owned forests (provided by the Forest Service, Department of Agriculture, Food and Marine) and for state owned forests (provided by inventory branch of Coillte, the state forestry agency). Stands containing Japanese larch (149,837 ha), hybrid larch (12,964 ha) and European larch (5,777 ha) amount to a gross area of 165,362 ha, and 3,093 ha stands contain multiple larch species (Figure 1). Of the stand area containing larch, 56% (93,048 ha) was classified as being in private ownership and 44% (72,314 ha) owned by Coillte. Initially, all sub-compartments were selected in both databases containing larch species either in pure or mixed stands. For mixed species stands, the area occupied by each species was assessed by multiplying the stand area by the proportion of the canopy cover represented by each species. Stand details (e.g. ownership, age, canopy cover, yield class[1]) and site parameters (elevation, mean annual temperature, degree days and average wind speed) were derived from a digital elevation model and spatial climatic data (Met Eireann 2017, Sweeney and Fealy 2003) processed within a Geographic Information System (GIS). The soil type for each stand including larch species was identified using a digitised version of the General Soil Map of Ireland (Gardiner and Radford 1980) (Table 1).

Identifying potential alternative conifer species to replace larch requires an evaluation of the growth performance (yield class) of companion conifer species across a range of soil types. Suitable alternative species should show similar or higher levels of productivity on equivalent sites, and should represent a lower level of biotic risk, hence those species most at risk from existing invasive pathogens were excluded (e.g. Lawson cypress as susceptible to *Phytophthora* spp. and pines as susceptible to *Dothistroma* spp., respectively).

Relationships were examined between the productivity of Japanese larch and, where relevant, hybrid and European larch, and the alternative conifer species growing within the same stands (and it is thereby inferred under similar climate and soil conditions). The analysis were restricted to those mixed larch stands where larch canopy cover exceeded 20% (to minimise early growth competition effects). Finally, where productivity data were available, linear regressions between the productivity of Japanese larch and of alternative conifers (e.g. Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), grand fir (*Abies grandis* (Douglas ex D.Don) Lindl.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and western red cedar growing on the same sites) were used to develop equations to predict the potential yield class of those alternative conifer species based on the measured yield of Japanese larch on a given site.

[1] Yield class is an index of potential productivity of stands, based on a relationship between stand dominant height and age (Edwards and Christie 1981). In the inventory, procedure for measurement is to take the top height of the largest diameter at breast height tree within a 100 m^2 (200 m^2 in mixture) plot within the stand, with number plots increasing with sub-compartment area and number of species in mixture (minimum of 4 plots).

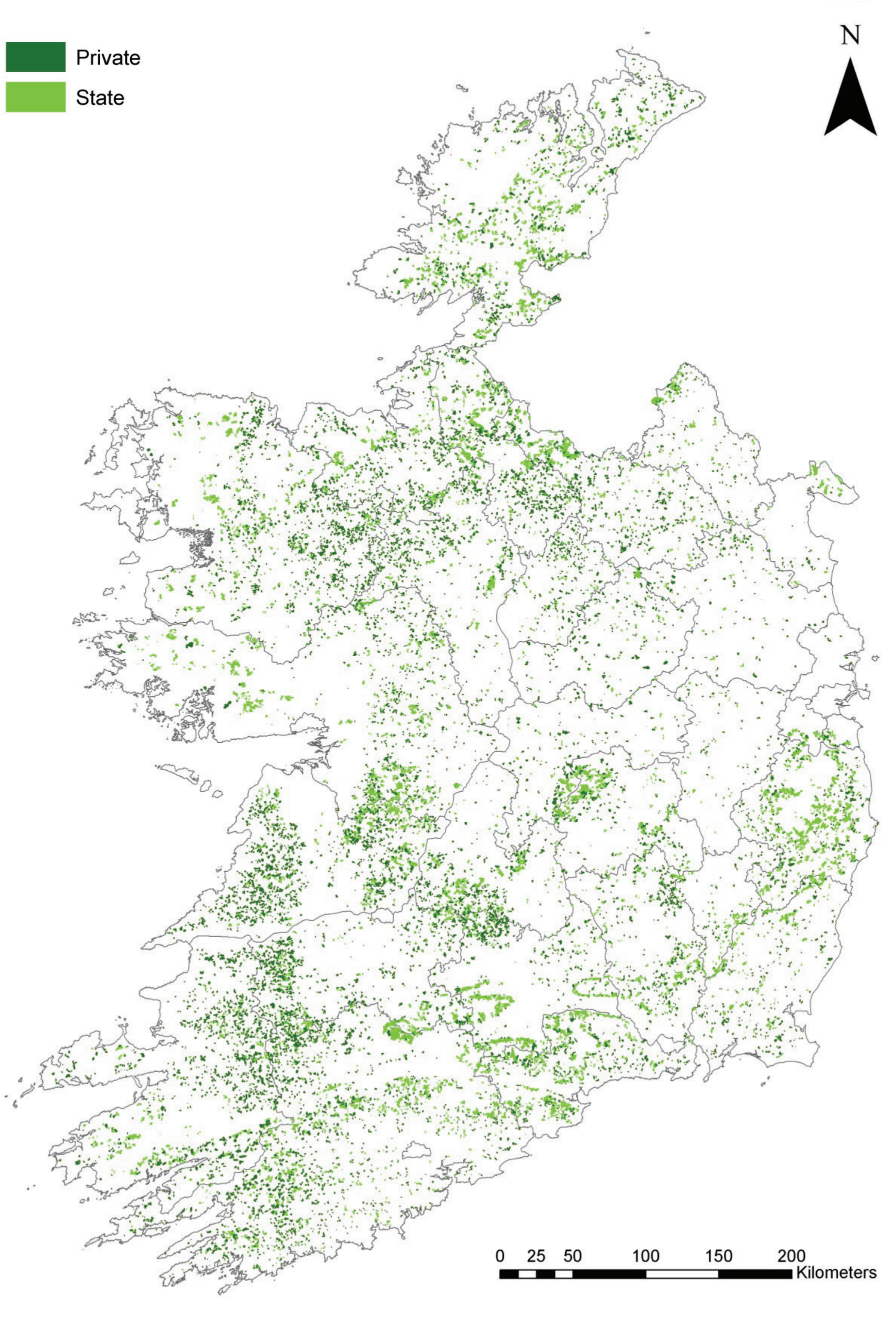

Figure 1: *Distribution of stands in the Republic of Ireland containing larch species under threat from* P. ramorum *distinguished by public and private ownership*.

Table 1: *Site characteristics including elevation (m), total area (ha) and average yield class (YC; m^3 ha^{-1} yr^{-1}) of areas planted with larch species classified by principle soil type.*

				Japanese larch				Hybrid larch				European larch			
				Pure		Mixed		Pure		Mixed		Pure		Mixed	
Soil[a]	Elevation[b]		Total area	Area	YC	Area	YC	Area	YC	Area	YC	Area	YC	Area	YC
ABE	104	(0-315)	2,025.8	252.7	10.2	1,264.5	11.3	98.6	12.4	220.6	12.3	35.0	7.3	154.6	7.5
BaP	72	(1-84)	1,348.5	41.3	11.8	1,146.5	10.6	11.1	7.6	96.2	11.2	11.7	6.0	41.6	7.7
BlP	183	(1-546)	4,998.3	624.4	8.8	4,062.0	9.5	18.3	11.5	233.7	10.2	15.3	8.0	44.6	7.2
BrP	176	(0-542)	5,735.6	944.2	10.2	3,911.9	10.5	169.7	11.3	506.2	11.5	36.6	7.1	167.1	7.3
G	123	(0-493)	8,476.6	739.4	10.0	6,731.9	10.8	84.4	10.9	659.8	11.4	82.2	8.0	178.8	7.3
GBP	88	(0-305)	2,775.5	170.4	11.0	1,949.6	10.5	48.1	11.7	201.2	11.2	137.3	8.0	268.9	7.4
L	163	(0-519)	542.7	83.3	8.4	422.8	9.8	6.8	10.0	22.8	9.3	1.4	6.0	5.4	5.6
PG	250	(85-421)	526.1	63.1	9.8	426.6	10.6	5.1	-	11.5	11.3	8.7	7.3	11.2	7.0
PP	220	(0-548)	4,176.4	718.4	9.4	3,070.7	9.9	45.2	10.3	182.0	10.7	43.9	7.0	116.1	7.1
P	175	(13-419)	986.2	116.0	10.3	669.3	10.4	15.1	11.2	79.8	11.4	4.3	8.0	51.8	7.2
R	167	(14-279)	49.1	3.7	9.0	35.6	9.1	0.6	-	0.3	-	1.0	-	7.9	6.8
SBE	53	(7-200)	362.5	84.2	8.6	224.6	9.3	1.0	12.0	31.7	11.5	7.8	6.0	13.1	7.1
OS	141	(0-253)	54.3	5.0	6.0	46.7	11.1	-	-	2.1	14.0	-	-	0.5	4.0
Total			**32,057.5**	**3,896.2**		**23,962.7**		**504.0**		**2,248.1**		**385.0**		**1,061.4**	

[a] Where ABE is acid brown earth, BaP is basin peat, BlP is blanket peat, Brp is brown podzolic, G is gley, GBP is grey brown podzolic, L is lithosol, PG is peaty gley, PP is peaty podzol, P is podzol, R is rendzina, SBE is shallow brown earth and OS is other soils.

[b] The range in elevation is included in brackets.

Results

The majority of the larch stock in Ireland (27,272 ha) occurs in mixed species stands and a smaller amount (4,785 ha) in pure larch stands (Table 1). The area occupied by hybrid larch (2,487 ha) and European larch (1,268 ha) is much lower than the area represented by Japanese larch (27,859 ha). Larch species have been planted over a wide range of site and soil conditions in Ireland. They are all found at elevations between sea level and 548 m a.s.l. for Japanese larch, to 447 m for hybrid larch and to 457 m for European larch; in low and high rainfall areas (Japanese larch from 692 to 3,022 mm, hybrid larch from 740 to 2,807 mm and European larch from 700 to 2,730 mm). In Ireland, larch species are subject to shorter and longer growing seasons with ranging degree days[2] for Japanese larch (534 to 2,149), hybrid larch (774 to 2,078) and European larch (916 to 2,117) indicating a wide geographic spread. A higher percentage of pure larch stands (64%), especially older stands of European larch, occur on well drained soils (brown podzolic, podzols, acid brown earths and grey brown podzolics). Occurrence on poorly drained soils (gleys, blanket peats and basin peats) was higher for mixed stands, typically where Japanese larch has been mixed with conifer species more suited to wetter conditions (i.e. Sitka spruce and lodgepole pine). This explains the increased planting of larch on gley soils over the period 1996 to 2010, reaching a peak in 2001 (999 ha), coinciding with grant aid for establishment of Sitka spruce/Japanese larch mixtures (Figure 2). The primary soil types planted over the period 1996 – 2010 were gleys (6,760 ha), blanket and basin peats (5,339 ha) and brown podzolic soils (4,318 ha) (Figure 2). Annual planting of larch declined dramatically after 2010 because of the outbreak of *P. ramorum* and decreased to virtually zero in 2014.

Of the Japanese larch mixed stands (23,963 ha), a significant proportion occurs on gley soils (6,732 ha), and this is also reflected in the location of hybrid larch mixed (2,248 ha) stands, with 660 ha found on gleys. The area of European larch mixed stands (1,061 ha) is primarily found on free-draining brown earth and podzolic soils (269 ha). The predominant companion conifer species for all larches is Sitka spruce, accounting for 18,870 ha or 79% of the area of Japanese larch mixtures, while also amounting to 1,540 ha and 238 ha of the area for hybrid larch and European larch mixtures, respectively. Other conifer species that represent a significant area in mixture with larches are lodgepole pine, Norway spruce (*Picea abies* (L.) H. Karst.), Douglas fir and Scots pine. The productivity of Japanese larch in mixed crops (10.1 m^3 ha^{-1} yr^{-1}) was consistently greater than in pure stands 9.7 m^3 ha^{-1} yr^{-1}) across a range of elevation categories up to 550 m. The exception is where Japanese larch occurs in mixed stands with less common conifer species such as noble fir (*Abies procera* Rehder) (8.4 m^3 ha^{-1} yr^{-1}) and European silver fir (*Abies alba* Mill.) (9.5 m^3 ha^{-1} yr^{-1}) (Table 2). The average productivity of hybrid and European larch in mixed stands is

[2] Degree days are the accumulated day-degrees above 5 °C which provides a measure of total heat accumulation.

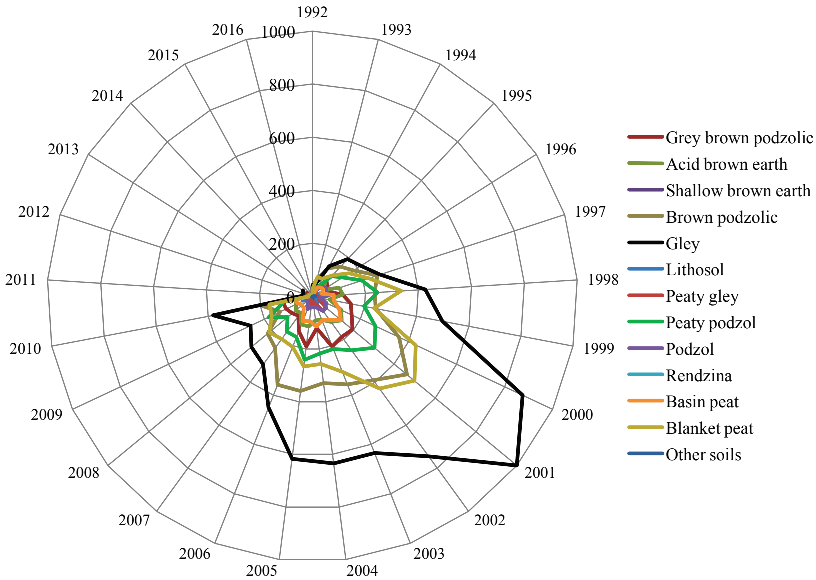

Figure 2: *Annual planting area (ha) for larch species on principle soils from 1970 to present.*

also often higher than that observed in pure stands of those larch species.

Significant correlations were found between the observed yield class of Japanese larch and the yield class of selected companion conifers growing on the same sites (r-values ranging from 0.49 to 0.70; $P < 0.01$) (Figure 3, Table 3). For Japanese larch, the highest correlation was found with the yield class of western hemlock, while for hybrid larch and European larch, the highest correlations were found with Douglas fir ($r = 0.73$) and Sitka spruce ($r = 0.61$) respectively. The explanatory power of linear regressions varied for different species combinations (r^2 of 0.24 to 0.48), with the regression analysis for western hemlock ($r^2 = 0.48$; $y = 0.7857x + 11.393$) displaying the strongest relationship with the yield class of accompanying Japanese larch ($P < 0.05$). Regression analyses was carried out for Douglas fir, noble fir, Norway spruce and Sitka spruce, stratified by the principle soil groups. These results indicated strong relationships between the yield class of Japanese larch and the yield class of Norway spruce growing together on basin peat ($r^2 = 0.71$; $y = 1.125x + 3$) and on gley soils ($r^2 = 0.50$; $y = 0.9364x + 6.6525$). The strongest relationship between the yield class of Japanese larch and the yield class of Sitka spruce was found on peaty podzol soils ($r^2 = 0.38$; $y = 0.956x + 8.0091$) although it explained a relatively low amount of the variability. A strong relationship was also found between the yield class of Japanese larch and the yield class of Douglas fir on podzolic soils ($r^2 = 0.76$; $y = 1.2632x + 2.6316$). These regression equations were developed to help predict growth performance of potential alternative species for larch sites.

A comparison of the performance (yield class) of companion conifers in mixed

Table 2: *Area of larch in mixture with each companion conifer species and productivity of larch in each mixture with productivity of companion species in parenthesis.*

Species	Area (ha)			Yield class ($m^3ha^{-1}yr^{-1}$)		
	Japanese larch	Hybrid larch	European larch	Japanese larch	Hybrid larch	European larch
Corsican pine	32	1	1	7.3 (7.5)	-	-
Douglas fir	495	33	45	10.9 (15.2)	11.5 (16.6)	7.4 (15.6)
European larch	60	11	385	9.9 (7.5)	12.0 (8.0)	7.3[b]
Grand fir	9	1	3	10.0 (16.4)	-	8.0 (17.1)
Hybrid larch	64	504	10	11.3 (10.6)	11.1[b]	8.0 (12.0)
Japanese larch	3,896	62	72	9.7[b]	10.6 (10.8)	7.5 (9.7)
Lawson cypress	30	41	34	10.4 (10.8)	12.0 (10.6)	-
Lodgepole pine (north coastal)	347	27	4	9.0 (10.6)	13.0 (9.6)	8.0 (8.0)
Lodgepole pine (other)	233	18	4	7.2 (6.2)	10.0 (8.0)	5.0 (6.0)
Lodgepole pine (south coastal)	545	45	10	9.0 (11.7)	11.1 (11.9)	6.0 (8.6)
Monterey cypress	5	1	3	-	-	8.0 (20.0)
Monterey pine	11	2	-	8.7 (15.5)	12.0 (14.0)	-
Noble fir	97	3	2	8.4 (13.2)	12.0 (13.0)	6.0 (15.1)
Norway spruce	568	36	133	10.6 (16.6)	12.3 (16.4)	8.1 (15.8)
Other broadleaves[a]	2,110	332	267	-	-	-
Other conifers	45	12	4	-	-	-
Scots pine	394	50	211	9.3 (9.0)	12.0 (9.8)	6.8 (8.9)
Serbian spruce	21	1	-	-	-	-
Silver fir	4	-	1	9.5 (15.4)	-	6.0 (10.0)
Sitka spruce	18,870	1,540	238	10.3 (18.9)	11.1 (18.8)	7.2 (18.5)
Western hemlock	23	23	17	10.4 (16.7)	-	8.7 (14.9)
Western red cedar	-	9	2	10.6 (17.2)	10.7 (14.9)	8.0 (17.5)
Total	**27,859**	**2,752**	**1,446**			

[a] Other broadleaves includes ash, birch, alder, etc.
[b] Indicates a single species stand.

Table 3: *Relationships and strength of relationships between larch and companion species.*

Species	Larch mixture	Soil	Count	Correlation	Standard error	Equation
DF	JL	All	97	0.53	2.85	y = 0.7287x + 7.0311
		Acid brown earth	25	0.68	2.73	y = 1.0471x + 3.5718
		Blanket peat	5	0.49	3.65	y = 2x - 6
		Brown podzolic	37	0.51	3.11	y = 0.7523x + 6.4885
		Gley	4	0.49	4.08	y = 0.6667x + 7
		Peaty podzol	14	0.60	2.11	y = 0.9194x + 5.7097
		Podzol	6	0.87	2.20	y = 1.2632x + 2.6316
GF	JL	All	11	0.55	4.92	y = 1.4167x + 3.1061
NF	JL	All	80	0.49	4.08	y = 0.8659x + 5.4482
		Blanket peat	15	0.56	4.41	y = 1.6731x - 1.1154
		Brown podzolic	17	0.69	3.73	y = 1.0024x + 5.154
		Gley	10	0.36	5.46	y = 0.6389x + 7.9444
		Peaty podzol	20	0.61	3.69	y = 0.9894x + 4.4868
NS	JL	All	92	0.57	2.57	y = 0.6386x + 9.9258
		Acid brown earth	8	0.27	2.49	y = 0.3636x + 11.818
		Basin peat	6	0.84	1.66	y = 1.125x + 3
		Blanket peat	7	0.50	2.42	y = 0.65x + 9.9
		Gley	15	0.71	2.07	y = 0.9364x + 6.6525
		Grey brown podzolic	26	0.46	2.66	y = 0.6014x + 10.322
		Peaty podzol	7	0.34	2.30	y = 0.2941x + 10.235
		Shallow brown earth	12	0.45	2.13	y = 0.3973x + 11.123
SS	JL	All	2,810	0.51	3.51	y = 0.8336x + 10.157
		Acid brown earth	92	0.53	3.22	y = 0.97x + 8.4557
		Basin peat	72	0.48	2.82	y = 0.6002x + 12.392
		Blanket peat	575	0.47	3.54	y = 0.7324x + 10.365
		Brown podzolic	534	0.51	3.28	y = 0.8615x + 10.048
		Gley	690	0.43	3.60	y = 0.1069x + 18.031
		Grey brown podzolic	130	0.32	3.09	y = 0.418x + 15.312
		Lithosol	71	0.55	2.61	y = 0.6672x + 10.36
		Peaty gley	56	0.23	4.88	y = 0.6229x + 13.348
		Peaty podzol	477	0.62	3.18	y = 0.956x + 8.0091
		Podzol	87	0.25	3.61	y = 0.3952x + 14.506
WH	JL	All	10	0.70	2.48	y = 0.7857x + 11.393
WRC	JL	All	7	0.50	5.12	y = 0.9111x + 6.7556
DF	HL	All	7	0.73	0.80	y = 0.8x + 8
NF	HL	All	5	0.31	2.50	y = 0.5x + 7.2
NS	HL	All	5	0.52	3.79	y = 2.25x - 13.5
SS	HL	All	172	0.28	3.08	y = 0.4344x + 14.262
DF	EL	All	21	0.10	3.63	y = 0.1878x + 14.188
NS	EL	All	23	0.45	3.52	y = 1.2302x + 7.0952
SS	EL	All	39	0.61	4.07	y = 1.7474x + 3.7103

[a] Where DF is Douglas fir, EL is European larch, GF is grand fir, HL is hybrid larch, JL is Japanese larch, NF is noble fir, NS is Norway spruce, SS is Sitka spruce, WH is western hemlock and WRC is western red-cedar.

stands with Japanese, hybrid or European larch indicates that Sitka spruce, western red cedar, grand fir, western hemlock, Norway spruce, European silver fir, noble fir and Douglas fir each show higher levels of productivity compared with the larch component across a range of soils (Table 4). Although the pines are currently under threat from *Dothistroma* spp., Monterey pine (*Pinus radiata* D.Don) and lodgepole pine (south and north coastal provenances) showed higher levels of productivity than Japanese and European larches, while Scots and Corsican pines show similar levels of productivity to these larch species, but lower levels of productivity than hybrid larch.

Discussion

This study has highlighted that 32,057 ha of larch species in Ireland are potentially vulnerable to the disease *P. ramorum*. While at first this may appear a relatively small area in terms of total forest extent, the widespread use of larch in mixtures, occupying an area of 165,362 ha (more than 20% of the total area of Irish forests), indicates a more serious issue than at first realised. Although Japanese larch is the primary commercial larch species to be affected by *P. ramorum*, hybrid larch and European larch can also suffer significant damage. In the past, on sites where Japanese larch has become infected, other species (e.g. Sitka spruce, noble fir) in the immediate vicinity have also become infected (but have not succumbed to the disease), which highlights the aggressiveness and adaptability of this pathogen (Brasier and Webber 2010). This is further illustrated by the original "jump" of the pathogen from *Rhododendron* into Japanese larch, which emphasises the uncertainty and unpredictability of the pathogen (Brasier and Webber 2010, O'Hanlon et al. 2016a).

It is possible that larch species have been deployed sub-optimally on poorly-drained soils (gleys, peaty gleys, etc.), often the result of Japanese larch being selected as the secondary species in mixtures with Sitka spruce, widely planted on poorly-drained soils in Ireland. The planting of hybrid and European larch reflects the deliberate policy of matching these species to free draining better-quality soils, whereas Japanese larch was commonly planted to fulfil the mixed species component and provide a contrast of colour in autumn. Much traditional species-site literature recommends the use of European and hybrid larches on moist to free draining soils (e.g. Savill 2013, Pyatt et al. 2001, Wilson 2011), while Japanese larch is believed to have greater tolerance of moist and wet soils (Pyatt et al. 2001). Our results suggest that where larch species are used to form pure stands, more attention is paid to planting the species on optimal soil types, suggesting that better drained and more fertile soils are selected to ensure success. For those minority of mixed larch stands, where Sitka spruce is not a component, it was not anticipated that the larch component would form a valuable part of the final crop, for example European larch in mixture with Norway spruce on frost-prone ground.

This study proposes potential alternative conifer species that offer productive

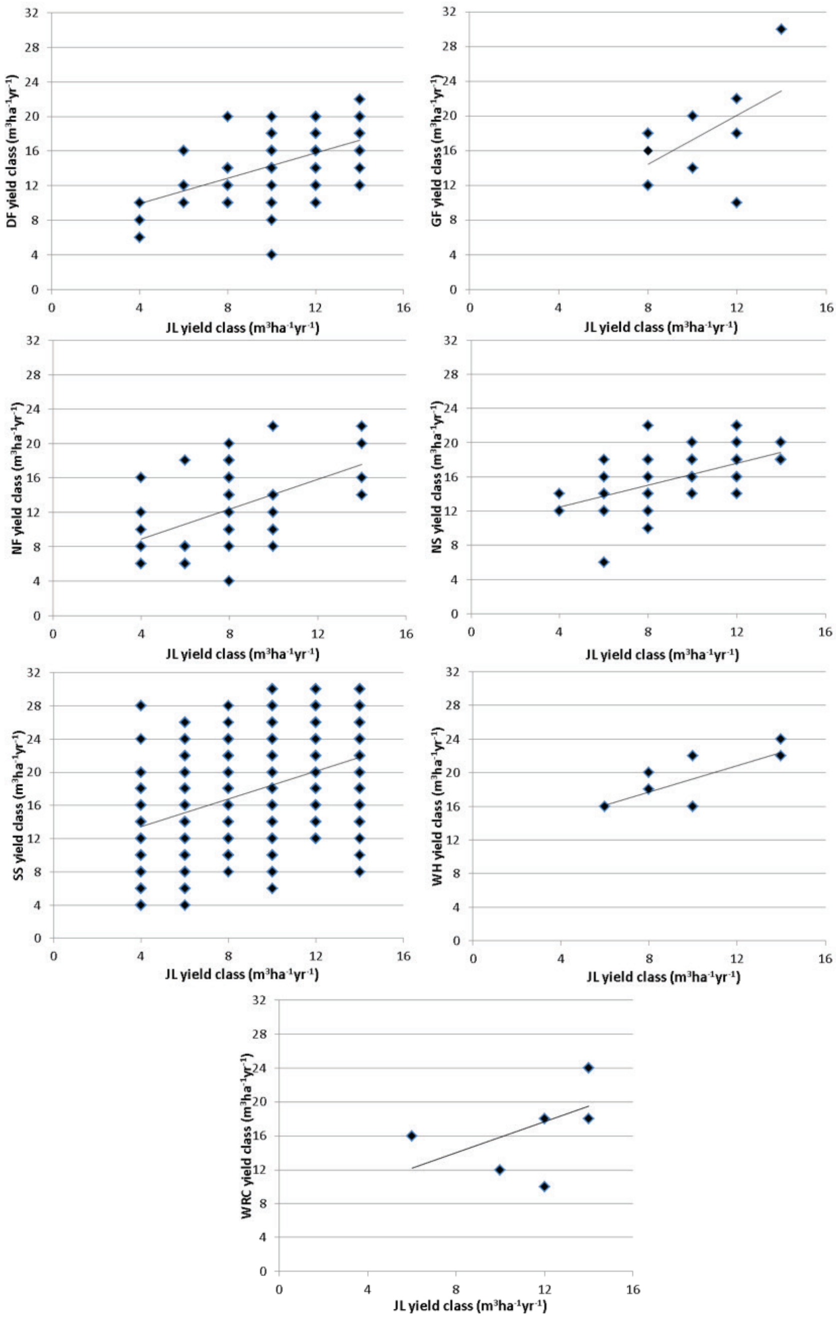

Figure 3: *A comparison of productivity (yield class) of Japanese larch (JL) with that of seven alternative species growing the same site with corresponding correlations in Table 4 (abbreviated species names as defined for Table 3).*

potential on a range of sites where larch is currently grown. Sitka spruce has been used extensively in mixtures with Japanese larch, and results presented here confirm that it remains a suitable species to replace Japanese larch on many sites. This is also the case for hybrid and European larch, where Sitka spruce is the most productive alternative across a range of soil types under current climate conditions. However, any increasing dependence on stands dominated by Sitka spruce comes with potential risks, and the use of alternative conifers in mixtures should be considered to reduce the impact of any potential future biotic attacks on spruce (Cameron 2015). In addition, challenges posed by climate change may necessitate a choice of alternative species better adapted to drier site types (e.g. rendzinas, lithosols, and shallow brown earths). Although Monterey and lodgepole pines can outperform larch species, they are susceptible to *Dothistroma* needle blight. Among the potential alternative conifers, Norway spruce, western red cedar, western hemlock, grand fir, noble fir, European silver fir and Douglas fir show productivity gains over the larch species when grown on suitable sites in each case. Our results and previous literature indicate that Norway spruce and western red cedar might prove useful alternatives on brown earth and brown podzolic soil characterised as being fresh to very moist in soil moisture regime (Pyatt et al. 2001, Wilson 2011, Wilson et al. 2017). Our results also suggest that these may be suitable alternatives for poorly drained gleys and cutaway raised bog soils under Irish conditions, although with uncertainty as to their performance (Horgan et

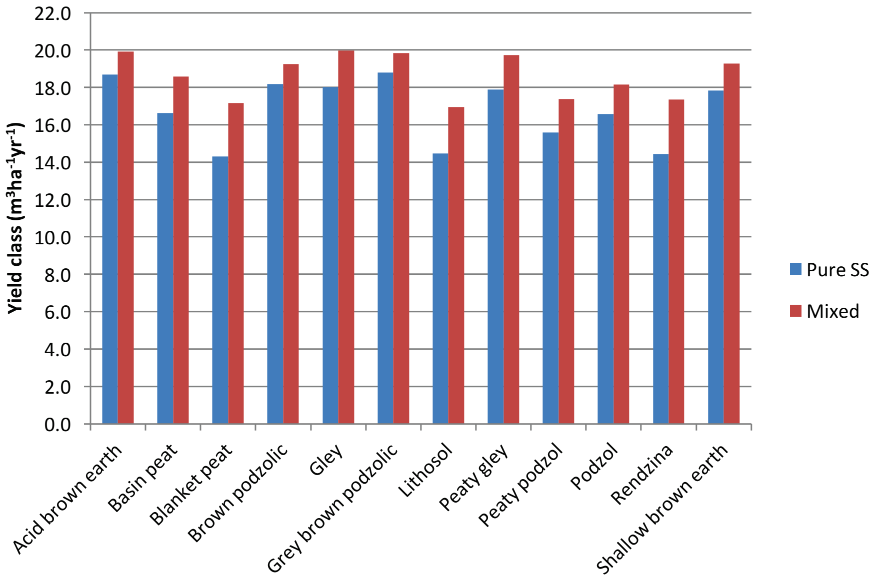

Figure 4: *A comparison of the productivity (yield class) of Sitka spruce (SS) growing in pure and mixed stands with Japanese larch stratified by principle soil type.*

Table 4: *Average productivity of each companion conifer species where found in mixture with larch, stratified by principle soil type.*

Principle soil type	Species[a] ($m^3 ha^{-1} yr^{-1}$)																
	CP	DF	EL[b]	GF	HL[b]	JL[b]	LC	LP	LPNC	LPSC	MP	NF	NS	SP	SS	WH	WRC
Acid brown earth	13.5	15.7	7.5	24.0	12.3	11.3	11.5	6.0		11.9	12.0	17.1	17.3	10.2	19.9	18.0	18.0
Basin peat		16.0	7.7	20.0	11.2	10.6	12.0		10.6	13.4	20.0		16.6	9.6	18.6	12.0	18.0
Blanket peat	9.0	13.7	7.2		10.2	9.5	4.0	7.4	10.0	11.3	14.0	12.4	15.7	8.7	17.1	18.0	15.3
Brown podzolic	8.3	15.2	7.3	16.7	11.5	10.5	13.7	12.0	9.3	11.7	15.0	14.4	17.2	9.1	19.1	18.4	16.7
Gley		14.9	7.3	26.0	11.4	10.8	14.0	4.0	10.3	12.2	14.8	13.8	17.9	8.9	20.0	16.0	20.0
Grey brown podzolic	10.0	15.4	7.4	17.3	11.2	10.5	8.0	8.0	11.0	12.3	12.0	13.4	17.5	9.8	19.8		19.3
Lithosol	12.0	15.2	5.6	11.0	9.3	9.8		7.3	9.8	11.7		12.8	19.5	8.4	16.9	12.0	
Peaty gley		13.3	7.0	16.0	11.3	10.6		10.0	12.3	9.4		13.0	15.3	8.0	19.7		
Peaty podzol	6.8	15.0	7.1	15.0	10.7	9.9		4.9	9.4	10.7	16.0	12.8	13.7	8.0	17.3	16.6	14.7
Podzol	8.0	14.4	7.2	18.0	11.4	10.4		8.4	11.1	12.9	12.0	14.3	15.2	9.6	18.5	16.0	
Rendzina			6.8			9.1				12.0			10.0	8.0	17.0		
Shallow brown earth		14.8	7.1	17.0	11.5	9.3	4.0		9.0	14.0		15.0	14.9	6.8	19.1	14.0	

[a] Where CP is Corsican pine, DF is Douglas fir, EL is European larch, GF is grand fir, HL is hybrid larch, JL is Japanese larch, LC is Lawson cypress, LP is lodgepole pine, LPNC is lodgepole pine (north coastal), LPSC is lodgepole pine (south coastal), MP is Monterey pine, NF is noble fir, NS is Norway spruce, SP is Scots pine, SS is Sitka spruce, WH is western hemlock and WRC is western red-cedar.

[b] Indicates a single species stand.

al. 2004). Grand fir, noble fir and European silver fir might prove suitable alternatives on sites classified as having fresh to moist soil moisture regime, including brown earths and imperfectly drained gleys. Although these *Abies* species display reasonable productivity and timber quality (Gil-Moreno et al. 2016), they are vulnerable to drought-crack on moisture limited sites (Savill 2013). Douglas fir and western hemlock might prove useful alternatives for drier sites, both being suited to slightly dry to fresh sites (Anderson 1960, Aldhous and Low 1974). Western hemlock also has the capacity to be extended onto gley soils and some better peats (Burns and Honkala 1990, Wilson 2011, Cameron 2015).

The study indicates that significant positive correlations exist between the productivities of Japanese larch and some companion conifers growing in the same mixed stands. The results of the regression analyses display relationships between the yield class of Japanese larch and companion conifers. For certain potential alternative species on common soil types, it allows the yield class of the alternative species to be predicted satisfactorily from the measured yield class for Japanese larch. We believe that this is a useful tool to assist in predicting the potential of an alternative species on a broader scale while also being assisted by average productivities of companion species across principle soil types (Table 3). Douglas fir, Norway spruce, western hemlock, western red cedar and grand fir (and to a lesser extent noble fir and European silver fir) may offer relevant alternative species with which to increase the resilience of our forests to biotic challenges, provide opportunities for silvicultural diversification and generate more diverse timber products. However, there are specific challenges to wider scale deployment of alternative conifers in Irish forestry. These include unknown risks of potential future biotic agents, increased establishment and maintenance costs (e.g. fencing costs to protect more palatable conifers from deer browsing) and incomplete information on provenance selection, silviculture, marketing and utilisation under Irish forestry conditions.

The selection of alternative conifer species for use in the area currently occupied by Sitka spruce and Japanese larch mixtures is necessary to mitigate future risks of biotic attack. Sitka spruce remains the "species of choice" during afforestation or restocking due to its impressive productivity across a range of soil types and established demand for its timber. In these Sitka spruce/larch plantations, the larch component was primarily used to enhance the landscape visually by providing autumn and winter colour. The autumn colours and deciduous nature of larch facilitated diversity in an otherwise blanket of dark green; it is likely that many conifers mentioned here will not fulfil this objective. Therefore, compatible broadleaved species may be required to improve the visual appearance of forests particularly in upland areas, however it is likely that productivity will be greatly reduced. This study also presented evidence of increased yield associated with Japanese larch mixtures. Japanese larch shows increased yield in mixture over pure stands and a further analysis of Sitka spruce in mixture with Japanese larch performed here indicates an increase in yield associated with mixed stands compared to pure Sitka spruce stands across a range of soils types (Figure 4). While it is known that larch may provide a nursing effect on Sitka spruce (OCarroll 1978), these results suggest that the positive growth effect may persist beyond establishment for both Sitka spruce and Japanese larch. Whether removing the larch in Sitka spruce mixtures may have a detrimental effect on the growth of Sitka spruce remains to be seen. Further research should examine potential nursing effects between other species mixtures.

Many Sitka spruce/Japanese larch mixed stands develop into a Sitka spruce monoculture with the larch component being thinned intensively or completely removed during thinning. Owing to the widespread use of Sitka spruce and Japanese larch mixtures, any replacement species should demonstrate a greater potential for retention to full rotation, be compatible with Sitka spruce (e.g. western hemlock) and offer potential as a nurse species which may assist with the successful establishment and development of the crop. It is likely that the more light-demanding or slower growing conifers may succumb relatively early in the rotation if not released by thinning. Mixtures with slower growing species or species with less dense canopies, such as pines and broadleaved species, may not provide sufficient crown-level competition to control branch and knot size, thus resulting in poor log and timber quality (Cameron 2015). Strategies to allow for the retention of minor species components in mixed stands need further evaluation to include the best methods of deployment including arrangement and composition and to determine whether intimate or non-intimate mixtures may afford greater flexibility in management.

Conclusions

This study suggests a number of alternative species to larch that display higher productivity on suitable sites and still offer lower levels of biotic risk compared to *Larix* spp. or *Pinus* spp. These include Douglas fir, grand fir, Norway spruce, western hemlock and western red cedar, with noble fir and European silver fir also having some potential utility. Depending on the site type, there may be opportunities to choose alternative species that fulfil specific biological or silvicultural functions (e.g. Norway spruce (for late spring or early autumn frost tolerance), Douglas fir (for drought tolerance), and western hemlock (for shade tolerance). Some may also offer enhanced opportunities for applications of alternative silvicultural systems, to improve biotic and abiotic resilience (Mason et al. 2012), assist stand diversification or increase total yield (Mason and Connolly 2014). There may also be a need to consider additional alternative species that are not the direct subject of this study (e.g. Japanese red cedar (*Cryptomeria japonica* (Thunb. ex L.f.) D.Don), coast redwood

(*Sequoia sempervirens* (D.Don) Endl.), Pacific silver fir (*Abies amabilis* (Douglas ex Loudon) Forbes)). Information about their likely performance on a wider range of site types is necessary before wider deployment could be recommended. Further research should focus on the use of mixtures of Sitka spruce with other Pacific coast conifers including Douglas fir, grand fir, western hemlock and western red cedar that may create alternative stand-level models for productive forestry as suggested for Scotland by Cameron and Wilson (2015).

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References

Aldhous, J.R. and Low, A.J. 1974. The potential of western hemlock, western red cedar, grand fir and noble fir in Britain. *Forestry Commission Bulletin* 49, HMSO, London.

Anderson, M.L. 1960. *The Selection of Tree Species: An Ecological Basis of Site Classification for Conditions Found in Great Britain and Ireland*. 2nd Edition. Oliver and Boyd, Edinburgh and London, UK.

Brasier, C.M. 2008. The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathology* 57: 792-808.

Brasier, C.M. and Webber, J. 2010. Sudden larch death. *Nature* 466: 824-825.

Burns, R.M. and Honkala, B.H. 1990. *Silvics of North America*. Volume 1. Conifers. Agriculture Handbook 654. U.S. Department of Agriculture, Washington, D.C., USA.

Cameron, A.D. 2015. Building resilience into Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests in Scotland in response to the threat of climate change. *Forests* 6(2): 398-415.

Cameron, A.D. and Wilson, S. McG. 2015. Alternative models for productive upland forestry: Model 2: Sitka spruce mixtures with alternative conifers. *Scottish Forestry* 69: 26-32.

DAFM. 2016. *Accepted Tree Species for the Afforestation Scheme*. Circular 5, Department of Agriculture, Food and the Marine, Dublin, Ireland.

Edwards, P.N. and Christie, J.M. 1981. Yield models for forest management. *Forestry Commission Booklet* 48. HMSO, London.

EPPO. 2003. EPPO Reporting Service 2003/09 [Online]. Available at http://archives.eppo.int/EPPOReporting/2003/Rse-0309.pdf [Accessed July 2017].

EPPO. 2010. EPPO Reporting Service 2010/09 [Online]. Available at http://archives.eppo.int/EPPOReporting/2010/Rse-1009.pdf [Accessed July 2017].

Gardiner, M.J. and Radford, T. 1980. *Soil Associations and their Land-Use Potential. Explanatory Bulletin to Accompany the General Soil Map of Ireland. A*n Foras Talúntais (now Teagasc), Oakpark, Co. Carlow.

Gil-Moreno, D., Ridley-Ellis, D. and McLean, P. 2016. Timber properties of noble fir, Norway spruce, western red cedar and western hemlock grown in Great Britain. *Forestry Commission Research Note* 26. Edinburgh: Forestry Commission.

Green, S. and Webber, J.F. 2015. *Pest risk analysis for* Phytophthora lateralis*, revised version 3*. Forest Research UK. [Online]. Available at https://secure.fera.defra.gov.uk/phiw/riskRegister/planthealth/documents/P_lateralis_PRA_February_15_version_3.pdf [Accessed July 2017].

Heslin, M.C., Blasius, D., McElhinney, C. and Mitchell, D.T. 1992. Mycorrhizal and associated fungi of Sitka spruce in Irish forest mixed stands. *European Journal of Forest Pathology* 22: 46-57.

Horgan, T., Keane, M., McCarthy, R., Lally, M. and Thompson, D. 2004. *A Guide to Forest Tree Species Selection and Silviculture in Ireland*. 2nd Edition. Ed. O'Carroll, J., COFORD, Dublin.

Hulme, P.E. 2009. Trade, transport and trouble: managing invasive species pathways in an era of globalization. *Journal of Applied Ecology* 46: 10-18.

Jones, D.R. and Baker, R.H.A. 2007. Introductions of non-native pathogens into Great Britain, 1970–2004. *Plant Pathology* 56: 891-910.

Levine, J.M. and D'Antonio, C.M. 2003. Forecasting biological invasions with increasing international trade. *Conservation Biology* 17: 322-326.

Mason, W.L. 2014. Long-term development of nursing mixtures of Sitka spruce and larch species in an experiment in northern Scotland. *Forest Systems* 23(3): 590-597.

Mason, W.L., Petr, M. and Bathgate, S. 2012. Silvicultural strategies for adapting planted forests to climate change: from theory to practice. *Journal of Forest Science* 6: 265-277.

Mason, W.L. and Connolly, T. 2014. Mixtures with spruce species can be more productive than monocultures: evidence from the Gisburn experiment in Britain. *Forestry* 87: 209-217.

McCracken, A. 2013. Current and emerging threats to Ireland's trees from diseases and pests. *Irish Forestry* 70: 36-60.

Met Éireann. 2017. *Rainfall Return Periods* [Online]. Available at http://www.met.ie/climate/products03.asp [Accessed March 2017].

OCarroll, N. 1978. The nursing of Sitka spruce: 1. Japanese larch. *Irish Forestry* 35: 60-5.

O'Hanlon, R., Grogan, H., McCracken, A., de la Mata Saez, L., Doohan, F., Jia, J., Harrington, T., Brennan, J. and Choiseul, J. 2014. *Understanding* Phytophthora ramorum *in Irish forests*. Factsheet printed and published via Teagasc.

O'Hanlon, R., McCracken, A.R. and Cooke, L.R. 2016a. Diversity and ecology of *Phytophthora* species on the island of Ireland. *Biology and Environment* 116B: 27-52.

O'Hanlon, R., Choiseul, J., Corrigan, M., Catarame, T. and Destefanis, M. 2016b. Diversity and detections of *Phytophthora* species from trade and non-trade environments in Ireland. *EPPO Bulletin* 46: 594-602.

O'Hanlon, R., Choiseul, J., Grogan, H. and Brennan, J.M. 2017. In-vitro characterisation of the four lineages of *Phytophthora ramorum*. *European Journal of Plant Pathology* 147(3): 517-525.

Pautasso, M., Dehnen-Schmutz, K., Holdenrieder, O., Pietravalle, S., Salama, N., Jeger, M.J., Lange, E. and Hehl-Lange, S. 2010. Plant health and global change – some implications for landscape management. *Biological Reviews* 85: 729-755.

Pyatt, D.G., Ray, D. and Fletcher, J. 2001. An ecological site classification forestry in Great Britain. *Forestry Commission Bulletin* 124. Edinburgh: Forestry Commission.

Read, D.J., Freer-Smith, P.H., Morison, J.I.L., Hanley, N., West, C.C. and Snowdon, P. (Eds.). 2009. *Combating Climate Change – a Role for UK Forests*. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The Stationery Office.

Savill, P. 2013. *The Silviculture of Trees used in British Forestry* (2nd Ed.). CABI, Wallingford, Oxford.

Stenlid, J., Oliva, J., Boberg, J.B. and Hopkins, A.J. 2011. Emerging diseases in European forest ecosystems and responses in society. *Forests* 2: 486-504.

Sweeney, J. and Fealy, R. 2003. Establishing Reference Climate Scenarios. Chapter 2. In *Climate Change Scenarios and Impacts for Ireland, Final report*. Environmental Protection Agency, Johnstown Castle Estate, Co. Wexford, Ireland, pp 5-31.

Wilson, S. McG. 2011. *Using Alternative Conifer Species for Productive Forestry in Scotland*. Edinburgh: Forestry Commission Scotland.

Wilson, S. McG., Mason, B., Jinks, R., Gil-Moreno, D. and Savill, P. 2017. The redwoods and red cedar: coast redwood (*Sequoia sempervirens*), giant redwood (*Sequoiadendron giganteum*) and western red cedar (*Thuja plicata*) – species, silviculture and utilisation potential. *Quarterly Journal of Forestry* 110(4): 244-256.

Webber, J.F., Mullet, M. and Brasier, C.M. 2010. Dieback and mortality of plantation Japanese larch (*Larix kaempferi*) associated with infection by *Phytophthora ramorum*. *New Disease Reports* 22: 19.

Timber exports in the south east

Niall C.E.J. O'Brien

What will we do now for timber,
With the last of the woods laid low.

Flood, 1999

So open the first lines of the poem on Kilcash in south Tipperary and the disappearance of Ireland's native forests which it portrays. Forestry and the timber trade in Ireland do not seem to figure highly in history books and historical journals, even economic journals. This may be in the belief that all the "woods [are] laid low" and there is little to talk about. This article examines the export trade in Irish timber over the centuries, charting its high point in the 17th century and its low by 1800 to the revival by 1914 with some account of the exports from ports along the south-east coast.

Pre-historic and Medieval times

After the end of the last ice age (about 12,000 years ago), tree cover slowly expanded to cover much of Ireland. The maximum tree cover was probably reached by 6,000 BC, after which a change in the climate and the spread of farming may have caused a decline. Some scholars suggest that Ireland was near treeless by the Bronze Age (c. 2000 BC) while others believe that the country had good tree cover up to the 12th century. The Brehon Laws categorised the different types of trees into four groups and imposed a variety of fines on people who illegally cut a branch off a tree or cut a whole tree down (Quinn 1994).

In 1224, timber was exported from Ireland for the construction of Salisbury cathedral while in 1250, timber was exported to build Marlborough castle. In 1224, Irish timber was exported to Winchelsea to make oars, galleys and long vessels (Sweetman 1974). In the second half of the thirteenth century, Queen Eleanor established timber works in Glencree Wood for the export of timber to build her caste at Haverford. In 1444, timber from around Shillelagh in Wicklow was exported to England to help build the King's College at Cambridge. Henry VIII also imported Shillelagh timber for his chapel at Westminster (Quinn 1994).

16th century

Over the centuries, the forests of Ireland became a place of refuge for Irish rebels and English outlaws. In 1399, Richard II employed 5,000 people to cut a gap through the Wicklow forests so he could overpower the MacMurrough nation, but the forests helped protect the Irish who wished to flee from the English. In Tudor times the forests of Ireland were still places of refuge and a "nursery of rebellion" (Quinn 1994).

Finding records of timber exports from Ireland in the 16th century is difficult, with the port records in England providing the best information. These records show that wooden boards were exported from Cork to Exeter, Plymouth and Padstow in the first quarter of the 16th century (O'Sullivan 1937). By the time of Queen Elizabeth, exports of Irish timber to England had increased considerably as there was a shortage of timber for charcoal and shipbuilding in England (Quinn 1994).

Not only did Irish timber exports to England increase towards the end of the 16th century but much of the timber was exported in processed form, ready to be made into oars, hop staves, ship planks and other products (Longfield 1924).

In the second half of the 16th century, coal exports to Ireland increased. In many cases southern Irish ports such as Wexford and Waterford exchanged this coal for timber, which was exported to Milford, Carmarthen and Cardiff (Longfield 1924).

A considerable amount of Irish timber was exported to Scotland in the 16th century, which was used to make ships that were subsequently used during military expeditions to Ireland (Longfield 1924). Such was the level of exports from some parts of Ireland that in 1579, Galway Corporation placed a ban on timber exports, largely because a scarcity of timber was driving up prices in the Galway area (Historic Manuscripts Commission 1885).

17th century

A vast quantity of hardwood timber was exported from Cork and Youghal by the New English settlers during the late 16th century and first half of the 17th century. This timber came from the river valleys of the Blackwater, Lee and Bandon and went into the manufacture of barrel-stave, charcoal and ship timber (Dickson 2005). Many of the Munster undertakers were reported to have destroyed large areas of woodland (Treadwell 2006). The destruction of the ancient woodland resulted in a reduction in the area used for refuge by outlaws and instead filled the pages of the poet's hand "Cad a dhéanfamuid feasta gan adhmad. Tá deire na gcoillte ar lár" (MacLysaght 1969).

The Nine Years War had a large impact upon trade. In 1603, an observer noted that New Ross was "A poor ruined town, out of trades", Dungarvan was "Only a very poor fisher town", while Kinsale was "A poor town ruined by the late rebellion". Of the southern ports, only Youghal received a favourable comment as "In slightly better position as the Munster undertakers carried on most of their traffic (especially wood) from here" (Peterson 1962).

Forestry as industrial fuel

In the 1580s, George Longe, among other people, came to Ireland to establish glass factories. The ancient forests helped provide the fuel for this new industry while at the same time "The project would allow the superfluous woods of Ireland to be cut as they were being now a continual harbour for rebels", as George Longe told Queen Elizabeth (Walsh 2001).

Pipe staves

Near where George Longe had his glass works at Curraglass, Co. Cork, a partnership was formed between Henry Pyne (local farmer), Veronis Martes (a Dutch merchant living in London) and Edward Dodge for the "working and making of pipe staves and other cask boards in various woods in Ireland" (Quinn 1966). In the 1590s, pipe staves were exported to Madeira, the Canaries, Bordeaux and La Rochelle. The trade was interrupted by the Nine Years War but resumed after 1601 with higher volumes being exported (O'Brien 2008).

From 1603 to 1633, pipe staves sold on average for £6/1,000 (c. €7.62/1,000[1]) in the southern ports with cutting and processing costing about 30s/1,000 (c. €1.91/1,000). An export duty of 6s 8d/1,000 (c. €1.69/1,000) was imposed in 1611 but the trade was still profitable (Treadwell 1998). By 1619, Sir Richard Boyle, a substantial landowner, had exported 400,000 pipe staves from Youghal. In the years 1616-1625, the port of Wexford (426,500 units) alone exported more pipe staves than Youghal (299,500 units) (Treadwell 2006).

The large quantities of pipe staves exported from Ireland to wineries in France and Spain must surely have displaced staves normally supplied from other countries. In 1591, a Dutch ship carrying pipe staves from Amsterdam was attacked by English pirates and her crew was put ashore on the west coast of Ireland. Many more Dutch vessels supplied pipe staves without incident. France and Spain were not the only destination for Irish pipe staves; in 1637, the *Whale* of London carried 63,000 pipe staves and 10,000 barrel staves from Ross to London (Appleby 1992).

Just as the destination of timber exports differed, so did the quality. The captain of the *Susan and Ellen* of London remarked in 1638 that 1,000 of the larger pipe staves loaded at Waterford and New Ross would take up as much cargo space as 1,100 of the smaller staves from Cork. The Cork pipe staves were also more crooked than those being exported from other ports, so care had to be taken during loading to minimise the amount of space they occupied in the vessel. A ship that could carry about 115 tons of wine could carry about 38,000 pipe staves while 1,000 staves roughly equalled three tons (Appleby 1992).

In 1615, a temporary ban on the export of pipe staves was imposed as the woods were being cut at an alarming rate, but Sir Richard Boyle got his friends in high places

[1] Monetary values have been converted to Euro equivalent, but not adjusted to real value.

to lift the ban and the trade continued. In the period 1616-1628, Boyle exported over four million staves or about 18,500 tons of timber. Much of this timber came down the River Blackwater in lighters and was reloaded at Youghal onto ships going to England, France and Spain. In April 1619, Richard Smyth, a lighterman, was paid £5/1,000 (c. €6.35/1,000) for carrying the staves to Youghal (Casey and O'Dowling 1964).

The large quantity of timber that was exported from Youghal in the 1620s and 1630s was done at a time when the local iron industry was developing. The timber was also used for making charcoal to fuel the furnaces. This large clearance of the ancient woodlands must have caused profound changes to the visual landscape.

Yet it seems that much of this timber came from upland areas and the actual area of farmland only increased slowly (Dickson 2005). Some arable farming was practiced up to 1685 in areas that had once being covered by forests. One of the reasons for the use of ploughing was to minimise the risk of breaking the plough on tree stumps. For the most part farming in the deforested upland only began in the 18th century, mainly in response to population pressure (MacLysaght 1969).

General timber exports

A large proportion of the timber in Ireland was exported from Wexford port in the early 17th century. In 1616-1625, some 476 tons were exported from Wexford, compared with 216 tons from Tralee and Dingle, the next largest exporters in the rankings. Smaller amounts were exported from other ports, with ports such as those in Dublin, Galway, Dungarvan and Waterford recording no exports of general timber (Treadwell 2006).

Shipbuilding

Shipbuilding was another market for Irish timber exports in the 17th century. One of the first recorded vessels, the *Seaman* of Camphire[2], to navigate the Munster Blackwater came upriver in February 1609 to load timber for the ship yards of Woolwich and Deptford. Local boatmen got 10 d (10 pence or c. 5 cents) per day for six days to load the vessel from lighters in mid river. There were no stone quays by the river bank then, unlike modern ports of the 21st century (O'Brien 2008). The abundance of oak, elm and beech (*Quercus*, *Ulmus* and *Fagus* spp., respectively) suited the shipbuilders, and the amount of timber of these species was running low in England. Yet sometimes the shipbuilders had to compete with those who used timber for making pipe staves. Several orders were made over the century to halt tree felling for pipe staves in order to increase the availability of timber for shipbuilding (Quinn 1994).

The Royal Commissioners in 1622 recommended a ban on tree felling within

[2] Camphire is the name of an ancient port in Zeeland, the western and least populous province of the Netherlands. This part of the Netherlands no longer exists due to land reclamation but Camphire operated as a port until at least 1710.

10 miles of the sea, a suspension of the pipe stave licence and an increase in the export duty on pipe staves in an effort to conserve timber for use by the navy. Some landowners like Calcott Chambers got around the 10-mile rule by promising his best trees for the navy. To help alleviate pressure on landowners within the 10-mile zone, it was suggested that commissioners would mark trees for the navy's use and allow the landowner freedom to cut the other trees (Treadwell 2006).

The tanning industry

A large part of the increase in tree mortality that occurred in Ireland in the 17th century was attributed to the tanning industry. The bark of both young and old trees alike was stripped, leaving the standing trees to die (Treadwell 2006). In the mid-1700s, Charles Smith suggested that the tannery industry in Cork was far smaller than it could be because of shortage of oak bark. This he attributed to the felling of large areas of forests in earlier years (O'Sullivan 1937). Nothing much happened after 1750 to increase the supply of native Irish oak and by the 1830s, considerable amounts of oak bark were imported into the country (Second Report of Railways 1837-38).

The iron industry

Another industry which consumed a lot of timber was the iron industry. The iron industry was established in the early 17th century on the Bandon River, in west Waterford and in Wexford. The industry was located in these places to take advantage of the great forests situated there at that time. Although there were local sources of iron, much of it was imported. The iron works, like the one illustrated in Figure 1, used large quantities of charcoal for fuel and many trees were cut down to satisfy demand. In 1626, it was said that only stubs of trees were left in the Tallow area and that by 1633, there was insufficient timber in the Bandon River valley to support the iron works. Sir Richard Cox, writing in about 1690, reported that "no care was taken in cutting down the timber to preserve a sufficiency for the carrying on of these works … all was destroyed here and a universal havoc made of root and branch in relation to west Waterford" (Cowman 2005).

In contrast to this, Professor Oliver Rackham's study into the iron industry in England concluded that, far from causing the destruction of the medieval forests, the industry fostered the retention and good management of these forests. Professor Rackham stated that "In all Ireland there was only one big wooded area which was just as extensive in 1840 as it had been in 1650, namely western Co. Waterford". In non-industrial counties like Limerick, Tipperary and Clare almost every scrap of woodland was lost (Rackham 1986). This area of western Co. Waterford was at the centre of a thriving iron industry from 1606 to 1640 and into the 1750s in some parts (O'Brien, 2008).

Thus, two different impressions of the forests of west Waterford are given

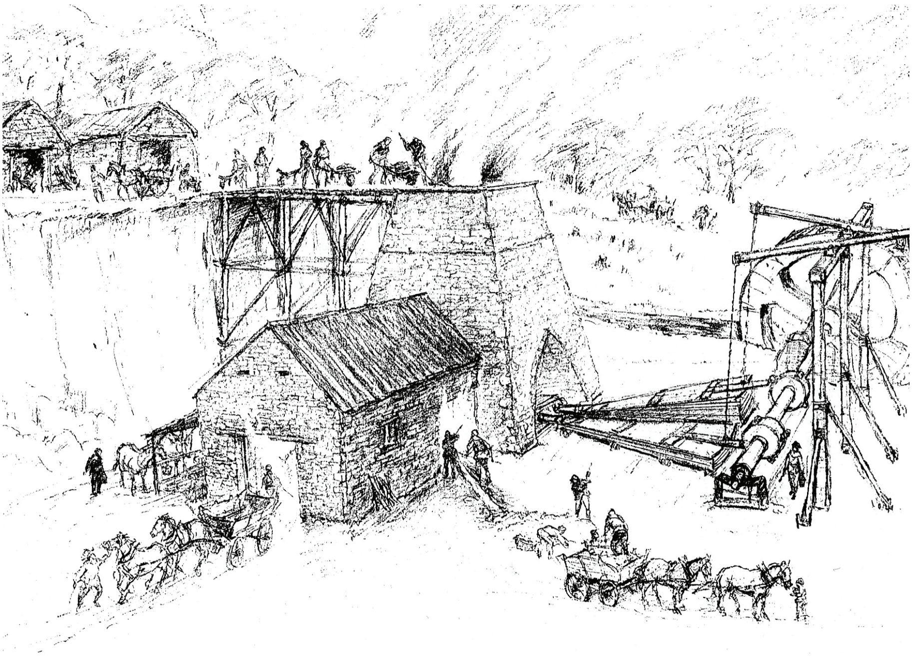

Figure 1: *Image of a typical 17th century iron works in Ireland. Drawing by Paddy O'Sullivan of Bandon (Cowman 2005). The iron ore and charcoal from the trees were loaded into a funnel in the centre of the tall stone structure inside which was the furnace. The water wheels at the side worked the bellows to generate a high-enough temperature to smelt the iron ore. The annexed building contained the casting area where the molten iron ran down channels creating iron bars. These iron bars were sent to forges nearby or exported to make all kinds of iron products.*

and both could be true and untrue at the same time. It seems that the demand for iron from Ireland after 1630 had decreased and the destruction of the iron works during the Confederate war (1641-1653) caused the decline of the iron industry (Power 2001). Thus, there was a decrease in the need to fell trees and the tree stubs of 1626 were just left to regrow naturally because there was little demand for charcoal.

Yet even the most conscious landowners could see that the forests of Ireland were being cleared at a rate beyond the level of regrowth. In 1673, Sir William Petty estimated that, even with the help of imports of Norwegian timber, the forests of Ireland would only last another 50 years (MacLysaght 1969). Yet even with the intense tree planting of Petty's descendants (c.1809-1817 and 1860s-1873) and the establishment of a tree nursery (c. 1800), much of the countryside between Kenmare to Derreen consisted of bare hillsides due to poor continuity management (Lyne 2006).

18th century forests

The heavy exploitation and felling of the Irish forests during the 17th century for iron, pipe staves, shipbuilding and tanning industries, with little in the way of substantial planting, meant that by 1711, Ireland was a net importer of timber (Quinn 1994). Even in the Irish Sea trade routes Irish timber was absent. By the mid-18th century, Waterford City was importing about 7,000 tons of coal per year but few pit props were exported. Many vessels bringing coal from Cumbria to Waterford returned empty (Mannion 1993). This was in contrast to the second half of the 19th century when Irish pit props were carried in exchange for British coal.

Yet there were other factors which contributed to the decline in the forest cover after the 17th century. Bad management of forest plantations was nearly as bad as not planting any new trees. In 1801, Frazer in his *Statistical Survey of County Wicklow*, blamed absentee landlords for the wholesale bad management of the forests of his day (Quinn 1994).

Others reported that it was the illegal cutting of trees by tenants and sometimes by the wood-ranger, along with the illegal tannery enterprises, that caused the destruction of trees by the stripping of the bark from oak trees. By the end of the 18th century, the demand for timber was so high that the looting of timber became a major problem (Crawford 2001). To combat this, trees were planted in groups rather than principally in hedgerows. But Arthur Young observed that the "stealing" of timber by tenants to make walking sticks, spade handles, cart shafts and roof rafters was nothing compared to the large amount of timber that was felled without any replanting (Quinn 1994).

Yet international competition (cheap New England timber in the 18th century) and internal competition for more grazing land contributed greatly to the decline in the forest cover in Ireland (Dickson 2000). Even in the 17th century, Dutch vessels were bringing in Baltic timber to Ireland (Dickson 2005). By the 1730s, the port of Cork and several ports in Ulster were importing timber from the American colonies in exchange for linen and butter (Dickson 2000). Yet Baltic timber was still popular and many Cork registered vessels travelled there for timber in the 1780s, while Norwegian vessels were often seen in Cork harbour during the Napoleonic wars. Elsewhere, there are plenty of references to Scandinavian vessels importing timber to Waterford in the 18th century (Mannion 1993). But after 1815, the vast bulk of imported timber came from North America (Dickson 2005).

In 1900, Professor Fisher of the Royal Engineering College stated that Irish farmers were short sighted, leaving over two million acres (809,371 ha) of waste land uncultivated when, if planted with trees, it could generate local employment and could be substituted for the nine million pounds (c. €11,427,643) of imported timber coming to England from such countries as Sweden, Norway and Russia (Agricultural 1900).

Yet much of the responsibility for land improvement was left to the tenant farmer while the landlord concentrated on infrastructure development like roads, fairs, flour mills etc. (Dickson 2000). As the farmers, even those who possessed a large holding, were mere tenants of the land, they tended to concentrate their efforts on livestock and tillage farming to earn a living. In contrast, the farmers would have to wait up to 30 years for the trees to grow large enough to generate a sufficient living income, by which time their land might have been confiscated. One writer, commenting on the short-term thinking among the people and the governments over many decades, dismissed forestry as a "long-term undertaking which can have no place in a [economic] programme which must be expected to reap immediate returns" (Clear 1949).

Rebuilding Ireland's forests in the 18th century

From 1634 to 1785 there were twenty-one acts of Parliament passed to preserve existing woodlands and encourage new plantings (Quinn 1994). But these seem to have done little to arrest the decline in forest cover. Paintings of various parts of the country, showing images of the same scene from different times, display the landscape full of trees in earlier paintings and a marked absence of trees in later images.

From 1765, a tenant with a lease of 12 years or longer could own his/her tree plantings. Western counties didn't take advantage of this provision while some positive reaction to the measures was registered in eastern and northern counties. However, tenant tree planting took off with gusto in Munster (except in Co. Waterford). There was a boom in tree planting from c. 1765 to 1815, but the amount of planting fell sharply in the agricultural depression of 1815 to 1820, and then resumed from then on (Smyth 1993).

Timber trade in late eighteenth century

The mixed management of Irish forests in the 18th century (varying between those who just chopped every tree in sight without replanting and those few who tried to replace the cut trees), coupled with international competition meant that by the end of the century Ireland was importing far more timber than it exported. Trade figures compiled in 1823 show increased volumes of imports between 1772 and 1817. The drop in imports in 1809 may be attributed to the 1807 Embargo Act passed by the United States of America which stopped trade with both Britain and France. Such was the small volume of exported timber that the custom officials didn't compile separate figures for timber, but instead included this information in the general trade data (see Table 1).

19th century plantations

At the start of the 19th century, numerous accounts in words and paintings were generated that leave us in little doubt that Ireland was nearly cleared of tree cover. The

Table 1: *Selected figures for imported timber from 1772 to 1817.*

Imported material	1772	1774	1793	1807	1809	1812	1817
Deals per hundred	10,030	10,828	15,840	21,712	1,753	18,377	6,985
Staves per hundred	43,594	23,445	43,448	56,648	24,323	71,069	54,886
Timber (tons)	6,064	14,277	29,651	10,582	8,775	32,829	32,400

Sources: Imports and Exports (1823) and Exports and Imports (1823). The parliamentary reports don't define what was meant by deals.

Statistical Survey of County Dublin, and similar publications for Wicklow, describe the rise of timber prices because of the scarcity of native trees (Quinn 1994).

Yet the times were changing and, as shown in Table 2, the area of tree cover increased considerably from 1791 to 1840, but still the amount of tree cover in Ireland was small by 1841. Some parts of the north midlands had 2% tree cover but other areas were barren. Many of the planted trees were in hedgerows and shelter belts rather than in plantations (Freeman 1957). Modern Co. Wicklow then had about 3% of its land in managed forestry with other areas, like steep valleys, having natural tree cover (Freeman 1957). Some of these trees were part of the 1821 planting by William Acton of 15,000 ash trees (*Fraxinus excelsior* L.) and 15,000 "Scotch fir" at Ballygannonmore in the parish of Dunganstown (Ainsworth 1967). Waterford had 5% of its land covered in forest, more than any other county (Freeman 1957).

Imported timber in early 19th century

The increase in forest cover made a slow impact on the timber trade and the first half of the 19th century saw Ireland import more timber than export. In 1814-1815, some 9,538 tons of timber was imported with Dublin (4,294 tons) and Cork (2,256 tons) dominating the trade with additional imports of deals and staves (Timber trade 1814-1815). In 1804, the port of Waterford exported bacon, salted meat and cereals using about 310,000 barrels with similar amounts and more in other years between 1800 and 1823 (Cowman 1993). This provided good employment in the cooperage industry, with the number of firms increasing from five in 1820 to 39 by 1839, but it provided questionable support to the native timber industry. Instead, around the same

Table 2: *Areas of tree plantings from 1791 to 1840.*

Planting period	Oak	Ash	Elm	Beech	Fir	Mixed	Total
Previous to 1791	9,220	1,083	201	380	652	30,994	42,530
1791-1800	604	375	55	155	503	9,065	10,757
1801-1810	537	279	54	138	1,089	12,580	14,677
1811-1820	564	275	53	113	2,224	17,352	20,581
1821-1830	543	179	57	295	3,110	20,824	25,008
1831-1840	484	254	154	243	2,636	22,537	26,308
Total	**11,952**	**2,445**	**574**	**1,324**	**10,214**	**113,352**	**139,861**

Source: Agricultural Statistics (1900).

time, large quantities of imported staves were imported into Ireland (Exports and Imports 1823). For example, in the 1760s, Walter Mullowney imported oak bark from Bideford in Devon for the tannery industry in Waterford. Devon merchants appear to have been the main exporters of oak bark to Waterford (Mannion 1992).

Timber at the ports

From 1825 to 1830 no timber was exported from Waterford port, but the import books reveal that oars, spares, staves, fir timber and oak timber were imported during the same period (Waterford Imports and Exports 1825-1830). Similarly, the port of Cork also reported that no timber was exported, but large quantities of timber were imported during this period (Cork Imports and Exports 1825-1831). The records for trade on the canals in Ireland showed a similar pattern for the first half of the 19th century, with much more timber being imported than exported. In 1845 for example, 1,386 tons of timber was carried on the Grand Canal to Dublin, yet 4,364 tons of timber was carried from Dublin port into the heart of the country (Delany 1966).

The 1835 and 1837 Report of the Railway Commissioners is often cited as a benchmark on the condition of Ireland's import and export trade at that time (Freeman 1957). These reports reveal little information in relation to timber trade in Ireland. The vast majority of timber was included under the category "other articles", so the level of timber trade was not specifically stated. Most of the recorded timber was imported oak bark for the tanners and mahogany for furniture (Second Report of Railways 1837-1838). In 1814, Ballymanus wood in Wicklow generated income of £1,255 (€1,419) from the sale of oak bark for the tanning industry but by 1835, this and other oak forests provided insufficient wood to satisfy domestic demand, so the remaining amounts had to be imported. The great oak forests of Shillelagh were becoming a memory (Quinn 1994).

Timber does not feature much in Irish exports before 1850, but there are a number of references to Irish-owned vessels carrying timber from Canada to England after taking passengers to the New World in the 1840s (Irish 2002). In the second half of the 19th century, timber features in the export figures for Irish ports. In 1834, Dungarvan exported no timber according to the records but in 1850, the schooner, the *Ruby*, exported timber from Dungarvan to Barry, Llanelly and Swansea in return for culm (Morris and Cowman 2014).

Internal timber trade

While timber was an insignificant item of trade according to civil servants in the 19th century, there was a gradual increase in the amount of timber traded within Ireland. In 1801, the Grand Canal Company carried 1,431 tons of timber, which had increased to 5,751 tons by 1845 and 16,850 tons by 1912. This increased demand for timber occurred even when the amount of building materials carried on the canal declined from 74,795 tons in 1845 to 36,721 tons by 1912 (Delany 1966). In 1812-1814, the Lismore Canal only carried about 8.5 tons of timber per year but by 1862-1865 this had risen to 146 tons per year and to 171 tons per year in 1866-1869 (O'Brien 2008). The competition between railway companies (and schooners on the River Blackwater) would have had an impact of these figures, but an increase in demand for timber occurred at this time.

Unfortunately, it seems that much of this timber was imported rather than native grown. In 1835, 12 tons of timber was carried up the River Boyne, but no timber went down river for export (Delany 1966). In 1847, over 28,000 tons of timber was carried inland from the ports of Dublin and New Ross on the Grand Canal system with only 1,329 tons of timber being carried to the coastal cities at this time (Delany 1973). The Lismore Canal in 1812 to 1814 carried an average of 8.5 tons per year from Youghal, but the record books do not indicate if this was native timber or imported timber (O'Brien 2008). This is unfortunate as the Blackwater valley was, and still is, an area rich in forest cover. Evidence from the River Slaney navigation records suggests that much of this timber could have been imported. In 1835, timber imports were the principal cargo on boats on the River Slaney, a heavily forested area (Delany 1966).

Late 19th century revival of forestry

It was estimated in 1884 that of the twenty million acres of land (809,371 ha) in Ireland, about a quarter could be used for forestry. To plant 100,000 acres (40,468 ha) with trees in 1884 would have cost about £4 per acre (c. €5.08/0.4 ha), with maintenance costs over the thirty years of about £20 per acre (c. €25.40/0.4 ha). The income from this forest, excluding intermediate cuttings, would, after thirty years, be about £50 per acre (c. €63.49/0.4 ha) (Howitz 1884). In 1885, Dr. Schlich conducted a report on the afforestation of Ireland and concluded that over two million acres (809,371 ha) was suitable for forestry at a time when 330,000 acres (121,405 ha) was in woods and plantations (Agricultural statistics 1900).

Rather than leave the development of Irish forests solely to private enterprise, it was suggested in 1884 that the government should establish a forestry department to develop nurseries and plant forests (Howitz 1884). Little was done to implement this recommendation.

In 1908, a committee of the Irish Department of Agriculture observed that "To conduct her agriculture and her industries and to maintain the life of her people at a normal level of efficiency and comfort, a nation requires to consume a certain quantity of timber" (Clear 1949).

The debate as to how much land should be devoted to forestry relative to the total land area of a country, or compared the area of agricultural land, had being ongoing since the second half of the 19th century, particularly in countries that had suffered from severe deforestation (Howitz 1884).

The English trade

The industrial revolution in England generated great demand for timber as pit props in the coal mines and for other uses. The construction trade accounted for about 36% of imported timber. In the 1870s, England was by far the biggest importer of timber in Europe with a demand of 290 million cubic feet (8.21 million m^3) compared to France in second place with 70 million cubic feet per year (1.98 million m^3) (Howitz, 1884).

In May 1870, Stewart Jameson of Whitehaven, Cumbria sought tenders in Ireland to supply 80,000 yards (73,152 m) of larch pit props to the ports of Dublin, Waterford or Cork. These were to be delivered at a rate of 8,000 yards (7,315 m) per month with free carriage to the ports (Waterford Chronicle 1870).

Forestry in the 1890s

In 1890, about 1.6% of the land area of Ireland was under forests. This amounted to 327,461 acres (132,519 ha) out of 20,328,753 acres (8,226,754 ha) and an increase of only 825 acres (334 ha) on 1889 compared to an increase of over 213,000 acres (86,198 ha) under pasture (Agricultural statistics 1890).

This was an increase on the acreage under forests of 304,906 acres (123,391 ha) in 1851, yet the increase was not uniform, fluctuating over the years. For example, in 1880 the area under forestry amounted to 339,858 acres (137,536 ha) (Agricultural 1900). In June 1890, about 1,400 acres (567 ha) were planted with trees, with larch trees accounting for a third of this. At the same time over 1,250,000 trees were felled (Agricultural statistics 1890).

In 1894, the counties with the largest proportion of forest cover were Waterford (4.6% of total land area), Wicklow (3.4%), Laois (2.5%), Down (2.3%), Tipperary (2.2%), Louth (2.2%) and Kilkenny (2%) with other counties below two per cent and Donegal (0.5%) with the lowest amount of forestry (Agricultural statistics 1894).

By 1900 the area under woods and plantations amounted to 311,648 acres (126,119 ha) or 1.5% of the land area. This was against a background of an increase in the land area covered by pasture and a decrease in the tillage area and a decline of 28,200 acres (11,412 ha) compared to the 1880 acreage for forestry. In contrast, England had 5.1% under forest, Scotland 4.5% and Wales 3.8% (Agricultural statistics 1900).

In 1900, the Irish Civil Service recorded that of the total forest cover in Ireland, larch accounted for 46,948 (18,999 ha), fir 34,677 (14,033 ha), spruce 16,478 (6,668 ha), pine 2,760 (1,117 ha), oak 24,711 (10,000 ha), ash 7,663 (3,101 ha), beech 10,052 (4,068 ha), sycamore 3,255 (1,317 ha), elm 3,048 (1,233 ha), other species 3,768 (1,525 ha) and 158,288 acres (64,057 ha) under mixed plantations (Agricultural statistics 1900).

In 1914, the counties with the largest forest cover by acreage were Cork (25,367 / 10,255 ha), Tipperary (23,910 / 9,676 ha), Galway (23,100 / 9,348 ha), Wicklow (19,121 / 7,738 ha), Waterford (18,159 / 7,349 ha), Kerry (14,271 / 5,775 ha), Down (12,472 / 5,047 ha), Laois (10,012 / 4,052 ha), Wexford (9,766 / 3,952 ha), and Kilkenny (9,678 / 3917 ha). The county with the least tree cover was Leitrim with 2,908 acres (1,177 ha) (Agricultural statistics 1914). Currently (2017), Leitrim is more associated with forestry than any other county. In 1914, some 814 acres (329 ha) was planted with about 1,826,000 seedlings (Agricultural statistics, 1914).

Tree felling in forestry operations in Ireland accounted for about 1,250,000 trees in 1890, about 933,021 trees in 1894, about 1,156,959 trees in 1900 and about 725,268 trees in 1914. The breakdown in the sales of these trees is shown in Table 3 (Agricultural statistics 1890, 1894, 1900, 1914).

A large proportion of the trees were used to make carts, wagons and farm implements in 1914, possibly reflecting the new tenant owners getting new carts and implements for their farms following the Land Acts. In 1914, larch trees made up the majority of timber going for pit props (179,274), paling (41,126) and cart and wagon making (60,485) and was the chief timber (11,321) used in the furniture and building trade (Agricultural statistics 1914).

Timber trade on the Blackwater during the 1880 and 1890s

From 1880 to 1889, over 21,000 tons of timber was exported directly from the rivers Blackwater and Bride using schooners and ketches and/or sailing vessels (O'Brien 2008). Local merchants, such as Michael Murphy, David O'Keeffe and Thomas Jacob, were the main timber traders on the River Bride (O'Brien 2008). From 1912 to 1916, David O'Keeffe owned a sailing vessel called the *Claggan* which was used to export timber and corn and to import coal (O'Brien 2008).

Local merchants such as John Stanley of Cappoquin, local landlords such as Villiers Stuart of Dromana, merchants from Cork such as Matthew McMahon and merchants from England such as Blood, Woolf and Company accounted for most of the timber trade on the River Blackwater in the 1880s (O'Brien 2008). Many of the

Table 3: *The usage of Irish timber in 1890, 1894, 1900 and 1914, expressed as numbers of trees felled.*

Year	1890	1894	1900	1914
Pit props	793,805	397,889	458,089	371,455
Sleepers	64,104	12,651	2,715	9,512
Palings and gates	23,238	56,322	29,277	61,977
Spools	23,000	1,252		9,368
Furniture and house building	30,806		10.411	22,785
Fuel		13,920	15,588	8,028
Carts and wagons	19,346	2,860	7,488	102,807
Clogs/shoes	10,574	2,088	2,170	3,510
Ship-building	11,590	1,015		1,525
Telegraph poles	5,750			

Sources: Agricultural Statistics (1890, 1894, 1900).

local and international traders exported timber and imported coal (O'Brien 2008). The two commodities suited each other. Timber was sent as pit props to England and Wales, which allowed the coal miners to dig deeper and extract more coal which was exported in return for more pit props. Pine forests were the best for pit props and railway sleepers (Howitz 1884). Of course, as often happens in the story of Irish forestry, not all pit props left Ireland. In 1886, the brigantine, the *Elizabeth*, imported 145 tons of pit props from Poole in Dorset to Limerick (Greenhill 1951). It is not known where in Limerick these pit props ended up.

In the 1890s, over 17,500 tons of timber was exported from the Blackwater and Bride rivers. Again, the Bride exporters were local merchants while a mixture of local and English merchants traded on the Blackwater (O'Brien 2008). The introduction of steamers onto the River Blackwater occurred in the 1890s, but these mainly engaged in the coal and grain trade. The sailing merchant vessels still carried most of the trade such as the *Dei Gratia* (the vessel that found the famous ghost ship, the *Marie Celeste*), the *Mary Haunsell* and the *William Edward* (O'Brien 2008).

Timber imports and exports at start of 20th century

In 1905, the value of imported timber was £1,152,025 (c. €1,462,738), compared to £227,802 (c. €289,249) for exported timber. Over the subsequent years the value of imports continued to far exceed that of exports as outlined in Table 4. Most of the imported timber was delivered to the ports of Belfast and Dublin, and to a lesser extent Cork, in the form of cut boards and finished furniture. The port of Dublin exported the most uncut timber and finished furniture (Report on Trade 1905).

In 1912, most of the timber imported was in the form of processed timber, whereas nearly 90% of the exported timber was rough timber, which the civil servants of 1912 stated was "an uneconomic condition of affairs". This was also true for other raw materials like hides, skins and wool for which Ireland exported the raw materials and imported the manufactured goods made from many of these same materials (Report of Trade 1912).

Similar to the situation for the use of raw timber, Ireland used very little timber from home-grown sources to manufacture goods in the early 20th century. Manufactured timber imports far exceeded Irish manufactured exports, as Table 5 below shows (Report of Trade 1912).

In 1912, Belfast accounted for the largest quantity of imported sawn timber,

Table 4: *The value of imported and exported timber from 1908 to 1912.*

	1908	1909	1910	1911	1912
Imported timber	£1,185,950	£1,360,665	£1,841,204	£1,735,953	£1,937,159
Exported timber	£237,173	£245,022	£240851	£251,452	£259,131

Source: Report of Trade, 1912.

boards and deals and furniture. Dublin exported the most in the way of furniture and clog blocks while Cork exported more rough timber. The southern ports of Waterford, New Ross, Dungarvan and Youghal dominated the pit props trade (Report of Trade 1912).

In 1914, an estimated 329,399 tons of timber was felled of which 215,380 tons was exported and the remainder used in Ireland. Sales of larch trees (112,245 tons) formed the majority of exports (Agricultural 1914). In 1914, Cork supplied the majority of larch trees while Limerick was first for the number of fir and spruce trees felled (Agricultural 1914).

Free State

The two World Wars took a great toll on the Irish forests. In 1938, it was estimated that only 1% of Ireland was covered by forests but by 1947, over half this area had been cleared (Quinn 1994).

Following the formation of the Irish Free State in 1922, the new Cosgrave government had the task of building a country and repairing an economy disrupted by years of war. The development of agriculture and ensuring the prosperity of the farmer were seen as important measures of success (Johnson 1974). Following the demise of landlordism, the state was the only organisation in the country that was actively managing forests in Ireland (Quinn 1994).

The new state didn't have it all its own way and faced strong competition from other countries in the export trade. For example, the export of pit props to England in return for coal imports was something that was not unique to Ireland. After 1918, France often became a destination for English coal in return for French pit props. A merchant at St. Brieuc offered Captain Shaw of the schooner, the *Kate*, to take pit props at 52s 6d (c. €3.34) per ton. The freight of coal was at a rate of 17s (c. €1.08) (Shaw 1972).

Timber exports from the River Blackwater in the 1930s

William Slade, a sailing merchant captain and ship owner from Appledore, remarked that after 1920, there was little trade available for the merchant sailing vessels except to Ireland. For the most part, this trade was one way, with coal to Ireland but returning light with an occasional cargo of scrap iron or potatoes (Slade 1959).

Table 5: *The value of manufactured timber imported and exported from 1908 to 1912.*

	1908	1909	1910	1911	1912
Imported manufactured timber	£1,130,446	£1,051,690	£1,141,529	£1,158,691	£1,272,372
Exported manufactured timber	£364,175	£310,376	£337,703	£333,193	£357,648

Source: Report of Trade, 1912.

Yet on the River Blackwater in Munster, there was considerable two-way traffic in the 1930s. In 1936, there were 15 sailings by various merchant sailing vessels carrying about 1,730 tons of timber and this increased to 21 sailings in 1937 and 2,349 tons, as detailed in Tables 6 and 7 below. In 1938, a total of 15 sailings left the River Blackwater after loading a total of 1,664 tons of timber. The vessels involved were the *Happy Harry*, the *Camborne*, the *Kathleen & May* (Figure 2) and the *M.A. James* (Youghal Harbour book 1936-1941).

In 1939, two vessels, the *Camborne* and the *Happy Harry*, accounted for the 14 sailings from the River Blackwater, with 1,535 tons of timber for the coal mines of Britain (Youghal Harbour book 1936-1941).

In 1940, there were 15 sailings from the River Blackwater with 1,735 tons of timber, mostly pit props. The vessels involved were the *Happy Harry*, the *Windermere*, the *Agnes Craig* (Figure 3), the *Eily Park*, the *J.T. & S.,* the *Frem* (Dutch vessel), the *Camborne*, the *Kathleen & May*, and the Purbeck (Youghal Harbour Book 1936-1941).

In 1938 and 1939, most of the timber was delivered via the River Blackwater but in 1940, a number of cargos of timber originated on the River Bride, a tributary

Table 6: *Two-way trade in coal and timber on the River Blackwater, 1936.*

Sailing date	Vessel	Entering	Sailing cargo	Load (tons)
11th Mar	*Harvest King*	Came light	Exported timber downriver	81
7th Apr	*Happy Harry*	Coal upriver	Timber from upriver	80
5th May	*Happy Harry*	Imported 5 tons timber to Youghal	Sailed light downriver	80
10th Jun	*Happy Harry*	Came light	Timber from upriver	80
18th Jul	*Happy Harry*	Coal upriver	Timber from upriver	80
19th Jul	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
11th Aug	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
12th Aug	*Happy Harry*	Coal upriver	Timber from upriver	80
3rd Sep	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
12th Sep	*Happy Harry*	Coal upriver Imported timber to repair Youghal Bridge	Timber from upriver	80
25th Sep	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
13th Oct	*M.A. James*	Coal to Youghal	Timber from upriver	87
14th Oct	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
17th Oct	*Happy Harry*	Came light	Timber from upriver	80
24th Nov	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
	Extra tonnage		30 tons by 15 sailings	450
Total	**15 sailings**			**1,730**

Source: Youghal Harbour book 1936-1941.

Figure 2: Kathleen and May *bound for Newport with the last cargo of pit props from Ballinacurra to the Bristol Channel in June 1960. Note the holds are full and the remainder of the cargo is on deck, making work for the crew difficult, and the temporary safety line rigged between the shrouds offered little protection. The long spar on top of the timber is a heavy gaff, specifically for cargo work. Photograph courtesy of the National Maritime Museum.*

of the River Blackwater. In 1940, three sailings with about 342 tons of timber were carried on the River Bride. Thus in 1940, some 1,393 tons of timber were loaded on the River Blackwater. The vessels, which were loaded on the River Bride, were the *Agnes Craig*, the *Happy Harry*, and the *Frem* (Camphire Bridge Log Book 1929-1956).

Timber exports from Ballinacurra after 1940

During World War Two, the small ports of Ireland mentioned above played an important role in the export of pit props to keep the British coal fields working, largely in return for coal. The scarcity of diesel curtailed road transport and the sailing merchant vessels could travel up rivers where the larger steamships could not go and collect timber from forests adjacent to the river. In 1940-1941, Mr. O'Keeffe, a coal, grain and timber merchant from Tallow, Co. Waterford, sent a number of vessels to Ballinacurra to collect pit props. Ballinacurra, on Cork Harbour, was better known for exporting grain and silica clay but as Table 8 shows, a considerable trade in timber was conducted over the 1942 to 1952 period. In 1940-1941, the *M.E. Johnson*, *Gaelic*,

Table 7: *Two-way trade in coal and timber on the River Blackwater, 1937.*

Sailing date	Vessel	Entering	Sailing cargo	Load (tons)
2nd Jan	*Happy Harry*	Coal upriver	Timber from upriver	80
3rd Feb	*Happy Harry*	Coal upriver	Timber from upriver	80
6th Feb	*J.T. & S.*	Coal upriver	Timber from upriver	83
9th Mar	*Happy Harry*	Coal upriver	Timber from upriver	80
15th Mar	*M.A. James*	Coal to Youghal	Timber from upriver	87
	Kathleen & May	Coal to Youghal	Timber from upriver	92
10th Apr	*Happy Harry*	Came light	Timber from upriver	80
19th Apr	*Kathleen & May*	Coal to Youghal	Timber from upriver	92
16th May	*Happy Harry*	Coal upriver	Timber from upriver	80
9th Jun	*Happy Harry*	Coal to Youghal	Timber from upriver	80
13th Jun	*J.T. & S.*	Came light	Timber from upriver	83
19th Jul	*J.T. & S.*	Coal to Youghal	Timber from upriver	83
24th Jul	*Happy Harry*	Coal upriver	Timber from upriver	80
18th Aug	*Happy Harry*	Coal upriver	Timber from upriver	80
11th Sep	*J.T. & S.*	Coal to Youghal	Timber from upriver	82
15th Sep	*Happy Harry*	Coal upriver	Timber from upriver	80
5th Oct	*Camborne*	Came light	Timber from upriver	79
14th Oct	*Happy Harry*	Coal upriver	Timber from upriver	80
28th Oct	*Camborne*	Coal to Youghal	Timber from upriver	79
18th Nov	*Happy Harry*	Coal upriver	Timber from upriver	80
19th Nov	*Camborne*	Coal to Youghal	Timber from upriver	79
	Extra tonnage		30 tons by 21 sailings	630
Total	**21 sailings**			**2,349**

Source: Youghal Harbour book, 1936-1941.

and the *J.T. & S.* left Ballinacurra with pit props while in 1942, Mr. Hyde of Fermoy exported pit props from Ballinacurra on the *Teasel*.

It should be noted that not every cargo of timber or pit props exported from an Irish port went directly to a British port. In 1948, Mr. O'Keeffe loaded the *De Wadden* with pit props at Ballinacurra for transport to Dublin (Figure 4). What became of the pit props once they reached Dublin is unknown (Ballinacurra Harbour Book 1934-1952).

In the earliest formation to pool resources, the Arklow shipowners acquired a 12-year-old German ship. The vessel had been taken as a war prize in 1945 by the British Admiralty and was sold in 1947 to the Arklow families and renamed *Tyrronell*.

The coaster *Tyrronell* derived its name from three letters chosen from the family surnames. The co-operative progressed when in 1966, Captains James Tyrrell, Michael Tyrrell and Victor Hall formed an umbrella company, Arklow Shipping, under which together they operated seven ships. Currently, Arklow Shipping is still one of the bright lights of Irish shipping.

Figure 3: Agnes Craig *loading pit props at Headboro on the Bride River (near Youghal), August 1948. Note the use of the cargo gaff and tackle to lift the logs on board. Photograph courtesy of Richard J. Scott.*

Figure 4: De Wadden *loading pit props at Killahala on the River Blackwater c. 1956. She was the last schooner to load there. Photograph courtesy of Richard J. Scott.*

400 years of change

After World War Two, timber was still loaded onto sailing vessels on the river Bride, but that mode of transport soon ended as the road transport infrastructure improved - another change in the 400 years of change for the Irish timber exports. The large steamships could only enter the larger ports, areas that were well served by the road network. The last vessel to leave the river Bride in September 1956, before the river was closed to commercial traffic, was the *Kathleen and May* and she carried a cargo of timber downriver (Camphire Bridge Log Book 1929-1956).

Currently (2017), the high ground along the valleys of the Blackwater and Bride rivers is covered with a mixture of farmland and forestry plantations, both privately and publicly owned. But instead of sailing vessels, the felled timber is transported by lorry to the larger ports of Cork and Waterford or to timber processing plants at Castlelyons and elsewhere. Yet the ever-changing nature of the timber trade now sees small ports like Youghal also playing a part in the modern timber trade. At Youghal, there is not only an export trade but timber is also imported, principally from Britain. This imported timber is processed at the Woodfad facility near Castlelyons and most is re-exported in manufactured form.

Table 8: *Timber exports from Ballinacurra, 1942-1952.*

Sailing date	Vessel	Timber load (tons)	Destination	Merchant
1st Sep 1942	*Brooklands*	135 tons pitwood	Cardiff	Hyde of Fermoy
23rd Jun 1948	*De Wadden*	240 tons pitwood	Dublin	O'Keeffe of Tallow
20th Aug 1948	*Tyrronell*	270 tons	Swansea	O'Keeffe
11th Sep 1948	*Tyrronell*	150 tons pitwood	Barry	Murphy
13th Nov 1948	*De Wadden*	210 tons	Garston	O'Keeffe
29th Mar 1949	*Empire Punch*	200 tons	Garston	O'Keeffe
5th Apr 1949	*Ange Ja*	110 tons	Garston	Nolan
21st Jan 1950	*Ceo Jean*	200 tons	Boston (UK)	O'Keeffe
14th Aug 1950	*Tyrronell*	260 tons	Garston	Haughton of Cork
5th Oct 1950	*Tyrronell*	220 tons	Garston	Hyde took the cargo from Haughton
21st Nov 1950	*Tyrronell*	250 tons	Garston	Haughton
7th Mar 1951	*Eban*	220 tons	Shoreham	Haughton
5th Jun 1951	*Tyrronell*	240 tons	Garston	Haughton
18th Oct 1951	*Bernard*	210 tons	London	Haughton
10th Jun 1952	*Tyrronell*	210 tons	Garston	Haughton

Source: Ballinacurra Harbour Book (1934-1952).

In our modern world we sometimes think of timber as an old fashioned raw material, yet demand for timber products is on the increase. The history of the Irish timber trade over the 400 years from 1600 to 2000 has been a picture of great highs and lows. Vast quantities of timber were exported from Ireland in the past, while at other times large quantities were imported. Currently (2017), Ireland exports a large amount of processed timber which is in contrast to the raw timber exported in the 17th century or even in 1912, when 90% of exported timber was described as "rough". Hopefully in future years the good performance of the Irish forestry sector can be maintained and no poet will have to write about the "last of the [Irish] woods laid low".

References

Agricultural Statistics of Ireland for the Year 1890. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/18507/page/493007 pp. 5, 25 [Accessed May 2017].

Agricultural Statistic of Ireland for the Year 1894. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/19261/page/519788 pp. 5, 8, 27, 36 [Accessed May 2017].

Agricultural Statistics of Ireland with Detailed Report for the Year 1900. British Parliamentary Papers. http://www.dippam.ac.uk/eppi/documents/20147/eppi_pages/552903 pp. vii, xxix, xxx, xxxi [Accessed May 2017].

Agricultural Statistics of Ireland with detailed Report for the Year 1914. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/22409/eppi_pages/631029 pp. 132-141 [Accessed May 2017].

Ainsworth, J. and MacLysaght, E. 1958. Survey of Documents in Private Keeping. In *Analecta Hibernica*, No. 20: 89.

Ainsworth, J. 1967. Survey of documents in private keeping. *Analecta Hibernica*, 25: 12, 42, 89, 90, 98, 143, 153.

Appleby, J. 1992. *A Calendar of Material Relating to Ireland from the High Court of Admiralty Examinations 1536-1641*. Dublin. pp. 64, 254, 255.

Ballinacurra Harbour Arrivals and Sailings Book. 1934-1952 (Manuscript in private keeping).

Camphire Bridge Log Book, 1929-1956 (Manuscript in private keeping).

Casey, A.E. and O'Dowling, T. (Eds.). 1964. *O'Kief, Coshe Many, Slieve Loughter and Upper Blackwater*. 15 vols. Wisconsin, vol. 6: 377.

Clarke, J. 2003. *Christopher Dillon Bellew and his Galway Estates, 1763-1826*. Dublin, p. 46.

Clear, T. 1949. Irish forestry to-day and to-morrow. *Irish Forestry* 6: 3-12.

Cork imports and exports, 1825-1831. *Account of Imports and Exports of Port of Cork, 1825-31; Tonnage of Ships, 1816-30*. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/10619/page/236298 pp. 4, 8-11 [Accessed May 2017].

Cowman, D. 1993. Trade and society in Waterford city 1800-1840. In *Waterford in History and Society*. Eds. Nolan, W. and Power, T.P., Dublin. pp. 427-458, at pp. 428, 457, 458.

Cowman, D. 2005. Evidence for pre-industrial mining in Waterford. *Decies* 61: 215-224.

Crawford, W. 2001. *The Management of a Major Ulster Estate in the late Eighteenth Century*. Dublin. pp. 34, 60-63.

Delany, V.T.H. and Delany, D.R. 1966. *The Canals of the South of Ireland*. Newton Abbot. pp. 65, 76, 149, 152.

Delany, R. 1973. *The Grand Canal of Ireland*. Newton Abbot. p. 255.

Dickson, D. 2000. *New Foundations Ireland 1660-1800*. Dublin. pp. 113, 114, 120, 123, 124, 132.

Dickson, D. 2005. *Old World Colony: Cork and South Munster 1630-1830*. Cork. pp. 20, 153, 154, 173, 174, 218, 220, 410.

Dooley, T. 1993. The Decline of the Ormonde Estate, 1893-1950. In the *Old Kilkenny Review, 1993*, Vol. 4, No. 5: 1118-1140, at pp. 1119, 1122, 1138, 1139.

Exports and Imports: Official Value of all Ireland, 1811-1822. 1823. British Parliamentary Papers. Wisconsin, http://www.dippam.ac.uk/eppi/documents/9694/eppi_pages/213312 pp. 4, 5, 8, 10 [Accessed May 2017].

Flood, J. and Flood, P. 1999. *Kilcash 1190-1801: Cad a Dheanfaimid Feasta Gan Adhmad*. Dublin, p. 88.

Freeman, T.W. 1957. *Pre-Famine Ireland*. Manchester. pp. 66, 79, 168, 185, 211.

Greenhill, B. 1951. *The Merchant Schooners, Vol. Two*. London, p. 169.

Howitz, D. 1884. *Forests and Waste lands (Ireland) Report, 1884*. British Parliamentary Papers. Wisconsin, http://www.dippam.ac.uk/eppi/documents/17627/eppi_pages/470427 pp. 1, 2, 3, 4, 11 [Accessed May 2017].

Historic Manuscripts Commission. 1885. *The Manuscripts of the Marquis of Ormonde, the Earl of Fingal, the Corporations of Waterford and Galway, etc. Tenth Report, Appendix Part V*. London, p. 430.

Imports and Exports of Ireland, from 25th March 1771 to 5th January 1811. 1823. British Parliamentary Papers. Wisconsin, http://www.dippam.ac.uk/eppi/documents/9695/page/213328 pp. 4, 6, 7, 8, 10 [Accessed May 2017].

Irish, B. 2002. Voyages of some Waterford-built ships for years 1840-1849. In *Decies*, No. 58: 53-60, at pp. 58, 59.

Johnson, D.S. 1974. The Economic History of Ireland between the Wars. In the *Irish Economic and Social History*, Vol. 1: 49-61, at p. 53.

Longfield, A.K. 1924. Anglo-Irish trade in the sixteenth century as illustrated by the English custom accounts and port books. In *Proceedings of the Royal Irish Academy*, vol. xxxvi, section C: 317-32, at pp. 326, 327, 328.

Longfield, A.K. 1946. *The Shapland Carew Papers*. Dublin. pp. 3, 4, 7-9.

Lyne, G. 2006. *The Lansdowne Estate in Kerry under W.S. Trench 1849-72*. Dublin. pp. 483, 485, 486.

MacLysaght, E. 1969. *Irish Life in the Seventeenth Century*. Shannon. pp. 8, 110, 136, 138, 139, 174.

Mannion, J. 1993. Vessels, masters and seafaring: patterns of voyages in Waterford commerce, 1766-1771. In *Waterford in History and Society*. Eds. Nolan, W. and Power, T.P, Dublin. pp. 373-402, at pp. 383, 385, 387, 390, 395.

Mooney, J. 2012. *The Changing Fortunes of the Headfort Estates, 1870-1928*. Dublin. pp. 14, 21, 38, 56, 59, 60.

Morris, J. and Cowman, D. 2014. The Dungarvan Ore Ships Part 1: The example of the coaster *Ruby*. In *Decies 70: 35-64.*

O'Brien, N. 2008. *Blackwater and Bride: Navigation and Trade, 7000 BC to 2007*. Niall O'Brien Publishing, Ballyduff Upper. pp. 36, 40, 41, 43, 44, 152, 156, 157, 205, 217, 221, 222, 271, 397, 451, 459, 465.

O'Sullivan, W. 1937. *The Economic History of Cork*. Cork. pp. 72, 73, 164.

Peterson. B. 1962. *Turn of the Tide: An Outline of Irish Maritime History*. Dublin, p. 34.

Power, T.P. 2001. Waterford's Iron Exports and the 30 Years War. In *Decies* 57: 1-2.

Quinn, D. 1966. The Munster Plantation: Problems and Opportunities. *Journal of the Cork Historical and Archaeological Society*. Vol. LXXI: 19-40, at p. 32.

Quinn, M.K. 1994. The evolution of forestry in County Wicklow from Prehistory to the Present. In *Wicklow History and Society*. Eds. Hannigan, K., and Nolan, W., Dublin. pp. 823, 824, 825, 827.

Rackham, O. 1986 and 2000. *The History of the Countryside*. J.M. Dent and Phoenix Press. pp. 91, 116.

Report on the Trade in Imports and Exports at Irish Ports during the year 1905. British Parliamentary Papers. Wisconsin. Available at http://www.dippam.ac.uk/eppi/documents/21099/page/585328 pp. xiv, 38, 39, 40, 41, 68, 69 [Accessed 14th May 2017].

Report on the Trade in Imports and Exports at Irish ports during the year 1912. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/22338/page/629209 pp. viii, ix, xxiii, 40, 41, 72, 73 [Accessed May 2017].

Second Report of the Commissioners Appointed to Consider and Recommend a General System of Railways for Ireland. 1838. Dublin, British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/11200/page/258543 appendix B. pp. 69-90 [Accessed May 2017].

Shaw, H. 1972. *Schooner Captain*. Truro. pp. 93, 97.

Slade, W.J. 1959. *Out of Appledore*. London, p. 89.

Smyth, W. 1993. Social, economic and landscape transformations in County Cork from the mid-eighteenth to the mid-nineteenth century. In *Cork History and Society*. Eds. O'Flanagan, P., and Buttimer. p. 659.

Sweetman, H.S. (Ed.) 1974. *Calendar of Documents Relating to Ireland Volume One, 1171-1251*. Liechtenstein, nos. 1196, 1232, 3090.

Timber trade. 1814-15. *Account of Quantities of Timber, Deals, Staves and Glass Admitted into Ports in Ireland, and Returns Relating to Suspension of Timber Duties, 1814-15*. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/8906/page/201785 p. 3 [Accessed May 2017].

Trant, K. 2004. *The Blessington Estate, 1667-1908*. Dublin. p. 141.

Treadwell, V. 1998. *Buckingham and Ireland, 1616-1628: a Study in Anglo-Irish Politics*. Dublin, p. 77.

Treadwell, V. (Ed.) 2006. *The Irish Commission of 1622: an Investigation of the Irish Administration 1615-22 and its Consequences 1623-24*. Dublin. pp. 14, 26, 87, 247, 283, 395, 396, 501, 728.

Walsh, T. 2001. *Sliabh Rua: a History of its People and Places*. Slieverue, p. 226.

Waterford Chronicle, 17th May 1870.

Waterford imports and exports, 1825-1830. *Account of Imports and Exports of Port of Waterford, 1825-30; Tonnage of Ships, 1827-30*. British Parliamentary Papers. Available at http://www.dippam.ac.uk/eppi/documents/10620/page/236314 pp. 4, 7 [Accessed May 2017].

Whyte, T. 2007. *The Story of Woodstock in Inistioge*. Dublin. pp. 57, 62, 68, 169, 322.

Youghal Harbour Arrivals and Sailings Book, 1936-1941 (Manuscript in private keeping).

Potential further development of forestry in Ireland – some observations from outside

Juergen Huss[a]

Preliminary remarks

The launch of *Broadleaf Forestry in Ireland* in late October 2016 presented an opportunity to reflect on the potential further development of forestry in Ireland. These are some thoughts and observations compiled because of my recent visit to Ireland.

Forestry in Ireland – historical perspective

History of forestry in Ireland

Approximately 1% of the originally extensive natural broadleaf-dominated forest cover was left in Ireland by 1900. Recognising this severe decline, and to meet the timber needs of the population, an extensive state programme of afforestation soon commenced which gained momentum, particularly after the two world wars. This programme resulted in the planting of predominantly exotic conifers and mainly on poorer sites. This was the result of a very low ceiling which was set on the price which the State would pay for forestry land to ensure that no land suitable for agriculture would be planted. Thus, over this period, state forests of about 400,000 ha or 6% of the state's area were established and have now facilitated the creation of a developing softwood timber market and a new wood industry. Since the 1990s, grants have been provided mainly to address the requirements for various agricultural products within Europe, including Ireland, and were designed to promote afforestation with broadleaves, partly to compensate for the predominance of the coniferous forests and partly because the sites which were by then becoming available in the private sector were of much better quality. Some 200,000 ha of pure broadleaf and mixed forests were established, and this was almost entirely privately-owned farm land. Thus, since the mid-1990s, a mainly private forestry sector has developed.

Natural preconditions

Ireland has a mild, moist oceanic climate, and although the climatic conditions vary considerably between the western and eastern part of the country, as well as between south and north, good forest growth is possible almost everywhere in the

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country. However, many of the sites in the lowlands are suitable for broadleaf species. Broadleaves in general are much more site demanding than most conifers and require a high level of soil fertility. Nevertheless, there are larger areas where mixed forests of conifers with broadleaves can be established.

Current situation

Ireland is in a good position in having extensive data to describe its national forest resources (National Forest Inventory – NFI 2007-2013) and, as mentioned, the conifer timber market is well-developed. Broadleaf timber, however, is still of minor importance, mainly because the majority of stands are still quite young, but they will gain significance as they age. The role of forests in nature conservation and recreation has also attained increasing public attention.

Silvicultural strategies and procedures for growing broadleaf forests (regeneration, thinnings, diminishing risks) are at a reasonable standard of development and most of these new broadleaf forests are at the earlier stages of management.

Options and demands concerning future development

Irish forestry will be increasingly influenced by external – worldwide – trends. Nevertheless, internal influences will likewise be important. Both aspects are discussed below.

Prerequisites for future development of Irish forestry

Forestry worldwide is confronted with some major issues which will gain increasing importance for all countries in the future. This is especially the case in Europe.

Climate change

Global warming threatens to result in more extreme weather events, such as more frequent dry periods (moisture deficits) and storms (catastrophic damages to forests). Even the political bodies in most countries are increasingly concerned about this phenomenon, and this problem is likely to provoke many more reactions in the future.

However, an increase in temperature may – other than in some tropical and subtropical regions – improve the growing conditions, especially for demanding broadleaves, and will be advantageous for forestry in Ireland and some other parts of the temperate zone. This will probably have a long-lasting effect. Therefore, broadleaves will deserve closer attention in the long run.

Role of forests as carbon sinks

The steady rise of CO_2-content in the atmosphere has provoked serious concern and discussion continues about reduction possibilities. Obviously, forests are the only terrestrial sinks of importance that can be regulated by man to any significant extent. Therefore, it can be expected that all states will face rising pressure to enlarge their forest area, to enhance tree growth and thereby intensify carbon sequestration.

In Germany for instance, where forest cover is at present 32%, the Society of German Foresters recently pre-emptively recommended an increase of this proportion to 40%, partly because of this reason, but also because the need for timber production will increase, and biodiversity will be enhanced.

Increasing needs of timber worldwide

According to data collected by the FAO over a period of 50 years (from 1960), timber use has increased as the human population has expanded, and there is little doubt that this trend will continue, at least for the next few decades (Figure 1). Timber and related products will, therefore, be needed in greater amounts in the future.

Renewable energy has become a big international issue. Wood from forests, but also open grounds, parklands and gardens, is currently one of the main sources of biomass and it is likely to grow in importance in the years ahead.

In some countries, like Germany, timber produced for energy use has increased and accounts for a surprisingly high proportion of the total wood output from forests (Table 1). Fuelwood and charcoal have been gradually replaced, first by hard and brown coal and later by oil and gas. Now this development has been reversed and there is no indication that timber for energy use will lose its newly-gained importance in the foreseeable future.

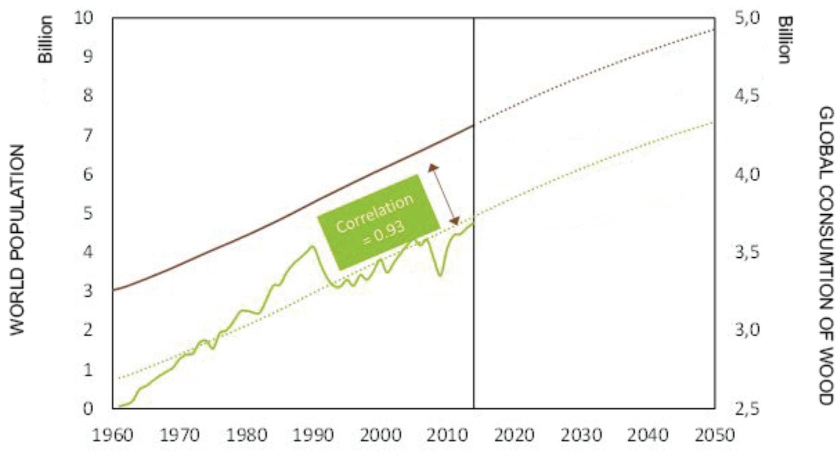

Figure 1: *Correlation between rising world population and timber consumption (FAO 2015). The upper line refers to the rise of world population until 2015 and World Bank forecast up to 2050. The lower (doted) line denotes global consumption of wood (m^3 $year^{-1}$) and its estimated development.*

Table 1: *Use of timber as source of energy generation in Germany.*

Year	Timber for energy use (%)
1800-1850	80 - 90
1925	40
1970	2
2015	40

Similarly, the emerging energy crisis has yielded its first advantages for Ireland's forestry as even small thinning material from young broadleaf stands can be harvested and sold more profitably than young conifers, whereas in the past, this material would not have been of any value and would have only represented a cost to the forest owner. This development has also added to the viability of such new developing broadleaf forests.

The amount of tropical timber available is decreasing and has become more expensive due to tighter regulation but is still needed for particular uses, such as in the making of fine (mostly expensive) furniture. This provides an opportunity for replacement by high quality (broadleaf) timber of local origin and sustainable production and it makes sense to increase the area of broadleaf forestry in Ireland to meet this developing need. It can be regarded as a general rule that markets tend to gradually become more differentiated and, therefore, need a greater range of timber species and qualities. This means that in Ireland, high quality broadleaf timber will gain importance in the longer run, partly to replace tropical hardwoods.

In the Strategic Plan for the Development of the Forestry Sector in Ireland of 1996, it was stated that, "Broadleaves are important because of both their high-value timber and their environmental role."

Urbanisation vs. rural depopulation

Urbanisation has become a worldwide trend as often the living conditions in rural areas are generally less favorable or lack work-related opportunities. In Ireland, however, the main reason may be the intensification and mechanization of agriculture, which releases people from farmland employment. Forests, however, if managed intensively, need higher manpower per area than agriculture, especially in extensive upland pasture systems in western and mountainous areas. The creation of new occupational opportunities in such areas would offer prospects to slow down migration into cities. Additionally, development of forests, recreational and/or nature conservation areas generate further opportunities for recovery and bring new forest education approaches and may even increase job opportunities to service these needs.

Overall, it can be concluded that the main external future prospects for further expansion of forests in Ireland seem promising and may open up new opportunities for implementing more intensive forest management practices.

Options for forest development in Ireland

Forests now cover roughly 9% of the land area of Ireland, in which conifers dominate (Table 2).

In 1996, a goal of 17% (about 1.2 million ha) of the productive planted forest area was suggested with an objective:

> To develop forestry to a scale and in a manner which maximizes its contribution to national economic and social wellbeing on a sustainable basis and which is compatible with the protection of the environment.

Such a target was originally stated in the strategic plan for forestry, *Growing for the future – A strategic Plan for the Development of the Forestry Sector in Ireland* (1996) and has more recently been reiterated in *Forests, Products and People – Ireland's Forest Policy, a Renewed Vision* (2014):

> To develop an internationally competitive and sustainable forest sector that provides a full range of economic, environmental and social benefits to society and which accords with the Forest Europe definition of sustainable forest management.

Thus, the international aspect, as well as sustainability issues, have now come more into the focus.

It is questionable as to what can and should be done to further develop forestry in Ireland. In *Broadleaf Forestry in Ireland*, the authors tried to envision the possible activities necessary to further develop Irish broadleaf forests. There are two possible options: conversion of existing forests and afforestation (Table 3) which are explained below.

Table 2: *Forest area of Ireland (according to NFI 2013).*

Forest type	Area (ha)	Area (%)
Conifers	440,000	69
Broadleaves	112,000	17
Mixed forests	88,000	14
Stocked area	**640,000**	**100**
Proportion of total land		*9.1*

Table 3: *Potential forest area available for conversion and afforestation with broadleaved species.*

Type of Land	Minimum	Maximum	Units
Conversion of existing forests to broadleaved	50,000	200,000	ha
cover	10	25	% land cover
Afforestation and conversion of non-forest	150,000	500,000	ha
area (e.g. grassland, scrub, cutover peat etc.)	3	10	% land cover
Total	**200,000**	**700,000**	**ha**

In detail, these options denote:

- Conversion of existing forests: While large areas of the broadleaf forests consist of mainly birch and willow stands, which are of low production, it is suggested that these areas should be re-evaluated with a view to be converted into units of higher production, mainly by means of under-planting. Moreover, forests of the former estates are often over-mature and degraded and should be regenerated. In total it is estimated that approximately 50,000 ha at a minimum, and possibly up to 200,000 ha, are available which seems to be a realistic, but still conservative, estimate.
- Afforestation: Afforestation of arable land will inevitably be more difficult and likely to provoke conflicts with agriculturists. Therefore, only sites that are not suited for agriculture have been included in our calculations which vary between 3 and 10% of the land area.
- A third possible option is for the State Forestry sector (i.e. Coillte) to be required to establish and manage a percentage of new broadleaf woodland each year, rather than its current almost exclusive coniferous woodlands. Again, this could be achieved by replacing some of the coniferous forests with broadleaves, particularly on good quality sites where broadleaf forests could be established very successfully and would be more likely to result in the production of quality hardwood logs.

Again, the above calculations are deliberately conservative. Nevertheless, it is estimated that between 200,000 and 700,000 ha of new forests could be established, which would lead to an increase of the forest area by a third, or more than double the current area.

In summary, there are large areas available for conversion into productive forests which would meet the above-mentioned challenges: rise of timber supply, fixation of carbon dioxide, creating more jobs in rural areas and providing recreational as well as nature conservation areas.

Currently however, the prospect of the above plans being realised in the next few years are low. Roughly 100,000 ha of forests have been established during 2003-2015, or 7,500 ha per year on average, but the yearly area declined from about 10,000 ha steadily to 6,000 ha per year within this period (Figure 2) and it is believed that the figures for 2017 have even dropped further.

Moreover, the proportion of broadleaf planting had diminished from $^1/_3$ to $^1/_5$ by the end of the period (2015). It may be assumed, therefore, that forestry has become less attractive for farmers and other landowners, and even disproportionately so for broadleaves. This may be due to insufficient encouragement through grant aid. Anyhow, there is a great gap between the current planting target of 6,000 ha per year and 15,000 ha which should be brought into production annually, based on the stated

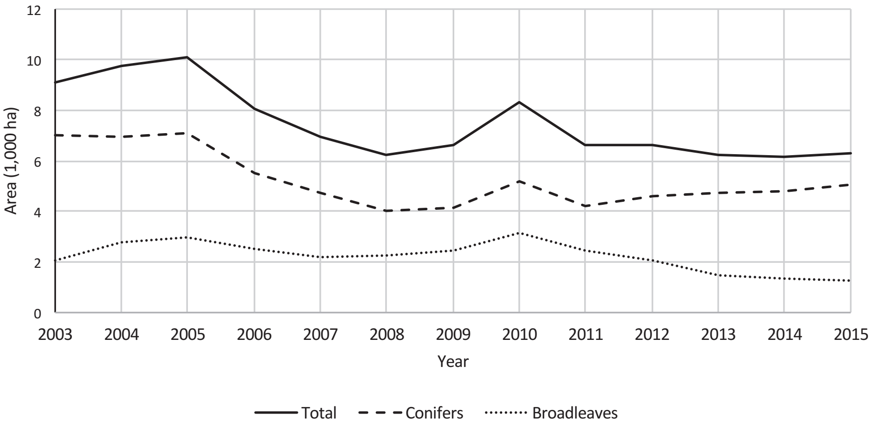

Figure 2: *Afforestation in the Republic of Ireland during the period 2003-2015 (Irish Timber Growers Association 2017).*

objectives in the renewed vision of forestry in Ireland (Department of Agriculture, Food and the Marine 2014). Apart from afforestation and the conversion of degraded forests, the Irish landscape offers great opportunities to improve the status of many hedgerows by enriching the most suitable ones with single broadleaf trees. Assuming appropriate tending and pruning, this would produce valuable timber and add to the beauty and biodiversity value of the countryside. Surprisingly, this issue, though practiced in several countries like the Netherlands, Turkey and Montenegro, is not mentioned in any forest policy statements. According to remote sensing inventories, hedgerows cover an area of c. 4%, thus offering another potential way of increasing national tree cover, especially of a broadleaved nature. Though not strictly forest area, such cover could contribute to many of the services provided by forests, assuming suitable management.

The present situation is somewhat comparable to that after the 2nd World War, when Clear criticised in 1948, "if forestry is to play its appropriate role in the future welfare of the country, we must plan anew the road ahead with **vision** [printed bold by the author] and courage. At present there is evidence of a spirit of lethargy which was foreign to Irish forestry in its earlier pioneer days" – and finally, "without a dream a people perish!"

Requirements for future development of forestry in Ireland

In order to implement and fulfill this ambitious programme, direct and indirect financial assistance, support and advice from the state agencies seem to be an indispensable requirement as follows.

Direct support

Several programmes that have been carried out for long periods will need to be continued in the long term:

- Allocation of grants for afforestation, conversion, tending and thinning of stands need further review and development. Early tending and thinning treatments normally do not cover the costs, but if these operations are delayed the quality of the resulting timber may be adversely affected. Therefore, grants are indispensable.
- Further improvement of the infrastructure network, especially forest roads.
- Training of forest workers (worker schools), as well as advanced education of forestry staff members. It is expected that annual harvesting of timber will double from 3.2 million m^3 yr^{-1} in 2010 to 6.5 million m^3 yr^{-1} by 2028. Therefore, many more work opportunities will result, and an increased and well-trained labour force will become necessary.
- Support and training of private forest owners.
- Their share of the workforce will increase as more forest establishment takes place mainly on the ground and they will need continuous training and support.

Although 6,000-7,000 ha have been afforested annually within the last decade – which is quite an impressive figure – another 100 years will be needed to double the forest area and to achieve the above-mentioned goals at the current rate. Thus, the efforts to expand the Irish forest area and its quality have to be markedly increased, upgraded and more fully developed, with deliberate efforts to improve biodiversity and social functions.

Forestry sector indirect support (e.g. a dedicated forest research organisation)

Irish forestry has now reached a reasonably well-developed position and will further gain increasing importance. To meet the above challenges, as well as to further improve its management standards, it needs a long-term and practice-oriented forest research organisation, similar to that in other countries with comparatively well-developed forestry industries. From experiences in these countries, such long-term and applied functions and requirements cannot be covered by institutions like the Forest Service, which is mainly bound to administrative duties, or by universities, which must concentrate preferably on short-term scientific projects. At one point, Ireland possessed an active forest research branch which was – unfortunately – abandoned in the 1980s. Similar sentiments were expressed by Clear in 1948 when he complained about the "absence of research." I find myself herewith repeating the mantra. Some specific areas that need attention include:

- monitoring of climate and soil development in the forest environment;
- studies of growth and yield (mixtures, exotic and other potential species, provenance trials);

- development of efficient methods of timber processing and enhanced forest infrastructure;
- monitoring of risks, diseases and damage to the forests and developing adequate counteractive measures;
- development of programmes for integration of forest management and nature conservation;
- development of programmes on environmental education, forestry education, recreation;
- close cooperation with universities and other research institutions;
- stronger links with similar organisations overseas.

Conclusions

The role of forests in the landscape and as places of employment will increase in the future. Forestry will provide retreat areas for fauna and flora, as well as sources of recreation and may become an important contact point with nature for the people. Forestry, therefore, is much more than timber production and this issue will become progressively more relevant as the industry grows and becomes sustainable.

Ireland has a substantial – possibly even great – future as a forestry country in the long run. To maximise this sustainable goal, however, long-term investment and increased cooperation are necessary. In addition, a greater commitment towards continuous development is essential and the potential negative effects of short-term political decisions and fashions on forestry need to be countered. Moreover, as science and research become increasingly sophisticated, developments in forestry also need more sophisticated, long term and multidisciplinary approaches.

Broadleaf forestry may still play a minor role for some time to come as compared with that of conifers, but – I am sure – it will gain increasing importance especially in combination with conifers, as mixed stands gain increasing importance and to improve the physical stability and biodiversity of forests. It is envisaged that the publication of *Broadleaf Forestry in Ireland* will help support this major future development.

Acknowledgement

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Literature

Clear, T. 1948. Does our forest policy need an overhaul? *Irish Forestry* IV (2): 49-58.

Department of Agriculture, Food and Forestry. 1996. *Growing for the Future – A*

Strategic Plan for the Development of the Forestry Sector in Ireland. Dublin: Stationary Office, p. 89.

Department of Agriculture, Food and the Marine. 2014. *Forests, Products and People – Ireland's Forest Policy – A Renewed Vision*. Department of Agriculture, Food and the Marine, Dublin, p. 75.

Huss, J., Joyce, P.M., McCarthy, R. and Fennessy, J. 2016. *Broadleaf Forestry in Ireland*. COFORD, Dublin, p. 496.

Irish Timber Growers Association. 2017. *Forestry and Timber Yearbook*. Dublin.

Monterey pine - a possible alternative species for commercial forestry in Ireland

John Fennessy[a*]

Abstract

In light of the effects of climate change on our forests, it is high time to consider alternative species which might be suitable for commercial forestry in Ireland. Given the limited number of species which might be suitable for establishment in this climate the choice is rather limited, however one such species is Monterey pine. This species is not new in Ireland and has been extensively planted here in the past. While the species natural distribution is very limited and confined to the coastal zone of central California and northern Baja, along with a few isolated island populations, it is grown in commercial plantations covering over 4 million ha throughout the world. However, in its country of origin it faces heightened conservation issues. From provenance tests undertaken with the species in Ireland, the most suitable for Irish conditions is the Guadalupe Island provenance. With greatest diameter growth rates, top heights and stem-form values, it is far superior to all other provenances tested and should be the recommended choice for future planting.

Keywords: *Climate change, alternative species, Monterey pine, provenance trial, Guadalupe Island provenance.*

Introduction

Climate change is increasingly recognised as one of the most important challenges facing society in the 21st century. A major feature of such change is its damaging impact on global ecosystems, particularly forests (Koskela et al. 2007, Black et al. 2010, Huss et al. 2016). According to the Inter Governmental Panel on Climate Change, likely changes in climate patterns could result in increases in average temperatures across Europe of 2–4 °C over the next 50 years and considerable changes in regional and seasonal patterns of climate. This is especially the case in relation to precipitation. Already these changes are being felt in some parts of Europe, for example the decline of pedunculate oak (*Quercus robur* L.) in the Loire region of France (Fennessy et al. 2016). These changes will alter the environmental conditions to which forest trees in Europe are adapted and will expose them to many new threats particularly new pests and diseases.

Already a number of tree species have become victims of the earlier onset of

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the effects of climate change and its damaging consequences and for some, their very survival may even be in doubt. An example of such change is the threat to ash (*Fraxinus excelsior* L.*)* from ash dieback disease (*Chalara fraxinea*) which has spread very rapidly across much of Europe. To counter these new challenges, foresters will, of necessity, have to consider new and alternative species which are suited to the new and changing climate patterns. In Ireland, the potential range of new commercial species is rather limited, never-the-less, in these changing climatic conditions, one such species worthy of reconsideration is Monterey pine (*Pinus radiata* D. Don). Monterey pine is not new to Ireland and has been widely planted here in the past and has already shown considerable potential. Monterey pine as a species is quite familiar in the Irish landscape and it has been extensively planted in arboreta and private gardens as individual specimens as well as a source of shelter in areas close to the coast. Irish foresters will be aware of its growth potential and its enormous productive capacity. It has many favourable attributes, including its short rotation length; it is a large volume producer and at the same time it provides excellent quality timber that is very durable. The species was originally introduced to Britain by David Douglas in 1833 (Savill 2013) and was probably brought to Ireland relatively soon after this date in the mid-1850s.

Monterey pine – a remarkable tree species

Alan Mitchell, in his *Gardener's Book of Trees*, suggests that the old name "*Insignis* pine" means "remarkable pine" and he suggests that in some ways, this is one of the most remarkable trees in the world (Mitchell 1981). Monterey pine is a forest tree species of great economic importance worldwide, although the species' natural range is quite restricted (see below). Monterey pine has proved very successful as a commercial exotic forest tree species in many parts of the world. The species is grown in commercial plantations on over 4 million ha but in its country of origin it faces heightened conservation issues (Vergas-Hermandez et al. 2014). As a species it is of major economic importance in many countries including New Zealand, Australia, South America and Chile as well as parts of southern Europe including Spain and Portugal. Large wood industries have developed around the species in many of these countries, sometimes entirely based on this species alone.

The natural range of Monterey pine

Monterey pine's native range is restricted to the coastal zone of central California and northern Baja, also in California, and a few isolated island populations (Vergas-Hermandez et al. 2014). However, the species formerly had a much wider distribution, as shown by fossil records, but due to an increasingly dry climate, the species declined to a few localities along the humid coastal belt of central California (Collingwood and Brush. 1979) with a latitudinal range of 35º to 37º. This limited natural range consists of scattered populations in small areas of Monterey County in California around the towns of Ano-Nuevo, Monterey and Cambria - the “fog belt” on the coast of California (Savill 2013) - and a further two populations on the Mexican islands of Cedros and Guadelupe (Figure 1). Collingwood et al. (1979) differentiated between the mainland populations (*Pinus radiata* D. Don) and the Guadelupe population, which they classified as Monterey pine (*Pinus radiata* var. *Binata* (Englm.) Lemmon), a related form to the mainland populations.

Monterey pine in Ireland – past experience

Monterey pine has been described as one of the most vigorous species ever introduced into Ireland and has been widely planted throughout the country. For what he termed the “British Isles”, Mitchell (1972) lists no less than twelve of the largest recorded trees of *Pinus radiata* in Ireland out of a total of sixty-four in this special category. These are recorded in a wide range of sites from Derreen Estate in Co. Kerry to Headfort Estate in Co. Meath and include Adare Manor, Co. Limerick; Collattin Estate, Co. Wicklow; Fota Island, Co. Cork; Muckross Estate, Co. Kerry; Powerscourt Estate, Co. Wicklow;

Figure 1: *Distribution of Monterey pine (red circles) along the west coast of North America.*

Inistioge Park, Co. Kilkenny and Emo Park, Co. Laois. While exceptional individuals can be found in the Irish countryside, very few fully stocked stands of good form exist and limited information on volume production potential in Ireland is available. Monterey pine accounts for 0.04% of the total Irish forest estate (NFI 2013). Although it grows almost year round, providing air temperatures are high enough, it does not suffer unduly from serious frost injury. Its vigorous growth-habit necessitates close spacing and continuous pruning for the production of high quality timber. For this reason it may also serve as an excellent agro-forestry species. Over the years, foresters have witnessed the spectacular growth rate of Monterey pine in Ireland and this has created much interest in the species, but difficulties in (1) establishment and (2) needle loss (yellows[1]) have been a major deterrent to the species being planted on a much wider scale in Irish commercial forestry.

Towards the end of the 1970s, a number of tree breeding programmes were established in Ireland including one focusing on Monterey pine (Pfeifer 1991) and although only a few provenance trials were established over the years (e.g. John F. Kennedy Arboretum in 1966), they were generally rather limited and did not cover the entire range. However, in 1978, tree breeders in Australia organised a provenance collection covering the entire range of the species which resulted in several trials in countries where it is of significant economic importance. As a consequence of this collection, a new provenance trial was established in Ireland at Bree Forest in Co. Wexford on a rich alluvial soil on the banks of the River Slaney in 1979. Here, thirteen sources were tested under Irish growing conditions from the species' natural range (source confirmed) along with one first generation Irish seed source from Shelton Forest in Co. Wicklow (unknown origin), as well as a source from a seed stand near Canberra in Australia. Results from the Bree trial suggest that the Guadalupe provenance from Guadalupe Island (Figure 1) achieved diameter growth rates, top heights and stem-form values far superior to all other provenances tested and this provenance has subsequently been considered the best and most suitable for use in Irish forestry (Lally and Thompson 2000). This provenance has the advantage that it does not suffer from needle loss (yellows), the needle cast disease which reduces productivity in Monterey pine. With an estimated yield class of 20 m^3 ha^{-1} yr^{-1}, this material would seem like the obvious choice in the event of a planting programme commencing at any time in the future. A past breeding programme also resulted in the selection of a large number of plus trees in older stands showing resistance to "yellows". As a follow on from this programme, open pollinated seed was collected

[1] A disease sometimes associated with the fungus *Cyclaneusma minus* or with climatic stress. The disease results in the yellowing and loss of the previous year's needles and a considerable loss in growth rate. The disease usually manifests after three to four years following planting. The consequent dying-off of immature trees can give rise to very open and heavily-branched stands. However, trees of the Guadalupe Island provenance appear not to suffer from this disease.

from these trees and over two hundred families were established in half-sib progeny tests. This programme commenced in 1979 and continued until 1985 when, due to a policy change, the programme was terminated.

According to Savill (2013), Monterey pine grows well on deep, dry, infertile sandy soils in the south of England and grows on loams and clay loams, but wet and shallow calcareous soils should be avoided. Similar soil and site types are considered suitable in Ireland but peats should be avoided. In Ireland, the mean yield class for the species has been estimated between 16 and 17 $m^3\ ha^{-1}\ yr^{-1}$, while the maximum mean annual increment occurs before the age of 30, which makes it a short rotation species and as a coastal species, it has a high level of exposure tolerance (Lally and Thompson 2000). Trees of up to 35 m tall occur in Britain and growth is rapid where the tree survives, while yield classes of 18-22 $m^3\ ha^{-1}\ yr^{-1}$ are common in the south-west of England (Savill 2013).

As already mentioned above, the Guadalupe Island provenance has proved the most suitable for Irish conditions, however, this source has been under severe pressure for many years and its very survival was, until recently, very much in doubt.

The Tree Council of Ireland, in its publication *Champion trees – A selection of Ireland's Great Trees* (2005) lists a number of *Pinus radiata* trees in the champion category. A specimen in Muckross, Killarney in Co. Kerry is recorded as a height champion with a circumference of 4.9 m and a total height of 45 m. Another specimen is recorded in Dereen Estate, also in Kerry, with a circumference of 9.0 and with a height of 31 m. In the section on girth champions for conifers, Monterey pine is recorded as having a circumference of 7.65 m and a total height of 33.5 m.

Future potential of Monterey pine in Ireland

The best information on suitable seed sources for Monterey pine for planting in Ireland suggest that only Guadalupe Island provenance be used in commercial forestry. However, in common with all populations of the species, this source faces heightened conservation issues. While the species in general has lost over 50% of its natural habitat, it is also threatened by various human-related disturbances. Monterey pine is on the IUCN (International Union of Conservation of Nature) Red List of threatened species, and the FAO Panel of Experts on Forest Genetic Resources has identified it as a species with high global, regional and/or national priorities for genetic conservation (Vergas-Hermandez et al. 2014). The Guadalupe Island provenance, which hosts one of the five remnant populations of Monterey pine, is considered particularly vulnerable. This population which is 250 km off the coast of Northern Mexico has survived under particularly harsh environmental conditions, with annual rainfall averaging less than 200 mm, although dense fogs are common in winter, especially at higher elevations. The evolution of the Monterey pine population on this island has remained isolated from the other island and mainland populations and has become genetically differentiated from them, showing distinctive morphological and adaptive traits (Vergas-Hermandez et al. 2014). The original pine population once occupied an extensive area on the northern end of the island however, even though the island has not been permanently inhabited by people, the pine population shrank dramatically in the last two centuries because of goats that were introduced in the mid-nineteen century preventing successful regeneration of the pines. The current tree population is down to somewhere over 200 over-mature individuals growing isolated in small patches in an environment hostile to establishment of new seedlings (Vergas-Hermandez et al. 2014). In 1981, the Guadalupe Island population of Monterey pine was declared "endangered" by the FAO Panel of Experts on Forest Genetic Resources, largely because of the grazing pressures from the introduced goats.

Conclusion

In the context of climate change and identifying suitable species for Irish commercial forestry, Monterey pine should be considered an important tree species and be given serious consideration. However, establishment difficulties and needle loss (yellows disease) have been recognised and need to be addressed. While it is an exotic pine which has been planted extensively in the past, it has shown tremendous potential in Ireland. Recognising the results from an earlier provenance trial, Guadalupe Island provenance has shown best overall performance in Ireland and is considered the most suitable provenance to plant. Seed sources may prove scarce however, as a species that has been widely planted throughout the world, securing a seed supply should not be too difficult. However, the choice of best provenance is vital to the success of the species.

References

Black, K., Xenakis, G. and Ray, D. 2010. Climate change impacts and adaptive strategies. *Irish Forestry* 67: 66-85.

Fennessy, J., Savill, P. and Clifford, B. 2016. Dynamic silviculture – an alternative approach to traditional oak silviculture. *Irish Forestry* 73: 217-238.

Collingwood, G.H. and Brush, W.D. 1979. *Know your trees*. Butcher, D. (Ed.). The American Forestry Association, Washington, D.C.

Huss, J., Joyce, P.M., MacCarthy, R. and Fennessy, J. 2016. *Broadleaf Forestry in Ireland*. COFORD, Department of Agriculture, Food and the Marine. Dublin.

Koskela, J., Buck, A. and Tessier du Cros, E. (Eds.) 2007. *Climate Change and Forest Genetic Diversity – Implications for Sustainable Forest Management in Europe*. Biodiversity International, Rome.

Lally, M. and Thompson, D. 2000. Monterey pine – the New Zealand "wonder tree" – does it have a role in Irish forestry? Information note no. 21. *Making Headways with Forest Research*. Coillte Research and Development, Newtownmountkennedy, Co. Wicklow.

Mitchell, A. 1981. *The Gardener's Book of Trees*. The Orien Publishing Group, London.

Mitchell, A. 1972. *Conifers in the British Isles*. H.M. Stationery Office, London.

NFI (National Forest Inventory). 2013. National Forest Inventory Results. Department of Agriculture Food and the Marine.

Pfeifer, A.R. 1990. *Studies of Provenance Variation in Conifer and Hardwood Species Grown in Ireland*. Report No 3/90. Coillte Teoranta, Research and Development. Newtownmountkennedy, Co. Wicklow.

Savill, P. 2013. *The Silviculture of Trees Used in British Forestry* (second edition). CABI International.

Vargas-Hernadez, J.J., Rogers, D.L. and Hipkins, V. 2014. Restoration of threatened *Pinus radiata* on Mexico's Guadalupe Island. In *The State of the World's Forest Genetic Resources - Thematic Study*. Genetic considerations in ecosystem restoration using native trees species. FAO, Rome.

Wu, J, Krutovskii, KV, Strauss, SH. Nuclear diversity, population differentiation, and phylogenetic relationships on RAPD and allozyme markers. *Genome*, 42: 893-908

Trees Woods and Literature – 41

Anton Chekhov (1860-1904)

The Russian playwright and short story writer, Anton Chekhov, was born in Taganrog, a port on the Sea of Azov in southern Russia in 1860 and died in Germany in 1904 while visiting a Black Forest spa seeking relief from tuberculosis. Despite his short life, Chekhov is regarded one of the greatest writers of short fiction in history. His career as a playwright produced four classics and his best short stories are now held in the highest esteem by writers and critics alike. Interestingly, Chekhov practiced as a medical doctor for most of his literary career: "Medicine is my lawful wife", he once said, "and literature is my mistress, when I get tired of one, I spend the night with the other".

When his father became bankrupt in 1876, the young Chekhov assumed the role of the family's bread winner while also paying for his education. During this period, Chekhov wrote for financial gain only. However, as his artistic ambition grew, he is credited with developing formal innovations which have influenced the evolution of the modern short story. Chekhov made no apologies for the difficulties this posed for his readers, insisting that the role of an artist was to ask questions, not to answer them. His writings belong in the same genre as Joyce and Beckett.

Figure 1: *Anton Checkov in April 1904. According to the Literature Museum Moscow, this was the last photograph to be taken of Anton Chehkov. Photograph courtesy of the Chekhov Museum in Badenweiler.*

During Chekhov's lifetime, Irish and British critics did not generally look kindly on his work. In fact, one of the earliest non-Russians to praise his plays was George Bernard Shaw, who subtitled his *Heartbreak House* "A Fantasia in the Russian Manner on English Themes," and pointed out similarities between the predicament of the British landed class and that of their Russian counterparts as depicted by Chekhov: "the same nice people, the same utter futility."

John McGahern was frequently referred to as Ireland's Chekhov and McGahern often spoke of Chekhov's influence on his own writing. However, it took twenty-three drafts of *The Bank Holiday* before he accepted Chekhov's famous advice; "It is not necessary to portray many main characters. Let two people be the centre of gravity in your story: he and she."

The Seagull was the first of Chekhov's plays and initially it was not a success. *Three Sisters*, *Uncle Vanya* and *The Cherry Orchard* soon followed. Following his death a fifth play, *Dead Centre*, was published after it was discovered in the vault of a Moscow bank where it had been deposited by his sister some years previously. Many of his plays have been performed in Dublin. It is reported that the late Cyril Cusack loved being cast in Chekhov plays.

For health reasons Chekhov bought an estate near Yalta in the Crimea where he planted trees, shrubs and flowers (Figure 2). According to his brother Mikhail, he "looked after these trees as though they were his children". Chekhov had an urban upbringing and studied medicine in Moscow, but in later life he spent long periods in the Russian countryside, either working as a doctor or on holiday. This led him to develop a deep love and appreciation of the countryside. His affinity with Russia's natural environment was evident in both his short stories and his travel writings. He wrote about a journey through southern Russia in *The Steppe* (1888) and he chronicled his expedition across Siberia to the Russian government's offshore penal settlement in Sakhalin Island. On that journey he encountered the taiga – vast coniferous forests of larch, spruce and pine – that lie between the steppe to the south and the tundra to the north. In central European Russia, by contrast, most of the indigenous forest consists of hardwoods, particularly birch and oak. Chekhov voiced his sadness at the destruction of ancient hardwood forests in his short story *Rothschild's Fiddle* (1894) and, more prominently, in his major plays. All of these are set in the wooded countryside of central European Russia and they were partly inspired by the long summer holidays he spent with family and friends in *dachas* south of Moscow. Despite his love of forests, Chekhov was more of a horticulturist than a woodsman.

The prominence of forests in Chekhov's plays reflected the landscape in which most Russians lived. In the early 20th century, 39% of European Russia was forested, though in some regions such as the areas south of Moscow where Chekhov spent much time, this proportion was more than two-thirds. The utilisation and exploitation of those forests was a matter of great public and private concern. The Emancipation Act of 1861, which freed the Russian serfs, left most forests in the hands of large landlords. More than half of the forests were owned by the State, a third by private landowners, with the remainder held by the Orthodox Church or the peasantry.

While living at Yalta he wrote his last play, *The Cherry Orchard*, in 1903. The fate of the orchard symbolises not only the end of the old rural social order but also

Figure 2: *Anton Chekhov in the White Dacha in Yalta. Photograph by Leonid V. Sredin in 1900 or 1901.*

the suburbanisation of the countryside. That process was already apparent in Russia by the early 20th century when it was facilitated by the rapid expansion of the railway network. The threats posed by suburban development were not confined to Russia. In England, as in Russia, many cherry orchards and suburban woodlots were also cut down and sold as building sites.

Despite the prominence of conservation issues in Chekhov's plays, he did not write them as clarion calls to action. He described both *The Wood Demon* and *The Cherry Orchard* as comedies, although they are comedies of manners and ideas, rather than comedies in their plots and situations. Chekhov did not side with either the conservationists or the developers because he believed that he had an artistic duty to present convincing portraits of characters with opposing views on all manner of subjects. The ensuing disputes are not resolved and that is one of the hallmarks of Chekhov's drama. Nevertheless, he strongly denied that he was bereft of principles and he was clearly concerned by the destruction of Russia's woodland environment. In that respect, his outlook mirrored that of contemporaneous conservationists abroad, such as John Muir, who campaigned to preserve the giant sequoias in the Sierra Nevada of California.

The rural world that Chekhov depicted came to an abrupt end with the Bolshevik Revolution in 1917. The new Soviet regime established state forest enterprises, which provided employment, amenities and products for local communities. Their focus, however, was on exploiting, rather than conserving the country's forests. Deforestation proceeded apace during the Soviet era and has continued to the present day, being exacerbated in recent years by the huge demand for timber from the Far East. Nevertheless, Russia still has more than one fifth of the world's forests – much more than any other nation. There are signs, moreover, that the Russian government is now more aware than its predecessors of the need to conserve the forests – for global, as well as national, reasons. President Vladimir Putin has insisted that any climate change pact must take into account the major role that Russia's forests play in soaking up carbon dioxide in the world's atmosphere. Chekhov would have welcomed this new concern for the conservation of the forests, but he would have been surprised that it is not universally shared.

Chekhov was a very complex man. We understand little about him, some say we know more about the enigmatic Shakespeare than Chekhov who, with an art peculiar to himself, in scattered scenes, in haphazard glimpses into the lives of his characters, in seemingly trivial conversations, has succeeded in so distilling the atmosphere of the Russia of his day that "we feel it in every line we read, oppressive as the mists that hang over a lake at dawn, and, like those mists, made visible to us by the light of an approaching day".

Always a very modest man, Chekhov could scarcely have imagined the extent of his posthumous reputation. Today, there are books of his famous quotes including the following: "Let us learn to appreciate there will be times when the trees will be bare, and look forward to the time when we may pick the fruit", and "Doctors are just the same as lawyers; the only difference is that lawyers merely rob you, whereas doctors rob you and kill you too"!

John Mc Loughlin

Book Reviews

A list of recently published books on trees and forestry which may be of interest to readers is provided below. Titles marked with an asterisk are reviewed in this section.

List of publications of interest to readers.

A Brief History of Trees by Gertrude Briggs. Published by Max Press. 2017.

A Tree Miscellany: An Eclectic Collection of Tree Related Trivia by Ian Parsons. Privately published. 2017.

Amazing Rainforest of Borneo by Huang Yi-Feng. Published by Natural History Publications Borneo. 2017.

Ancient Oaks in the English Landscape by Aljos Farjon. Published by Kew Publications. 2017.

Applied Tree Biology by Andrew Hirons and Peter A. Thomas. Published by Wiley-Blackwell. January 2018.

Around the World in 80 Trees by Published by Jonathan Drori and Lucille Clerc. Published by Laurence King Publishing. May 2018.

* **Broadleaf Forestry in Ireland** by J. Huss, P.M. Joyce, R. MacCarthy and J. Fennessy. Published by Coford. 2016

Costa Rica Magical Trees (2nd Edition) by Juan Pucci, Sergio Pucci and Giancarlo Pucci.

Domestication of Radiata Pine by Rowland Burdon, William Libby and Alan Brown. Published by Springer-Verlag. 2017.

* **Essential Pruning Techniques: Trees, Shrubs and Conifers** by George E. Browne (1917 – 1980) and Tony Kirkham. Photographs by Andrea Jones. Published by Timber Press. 2017.

Forest and Urban Tree Entomology by Jacqueline L. Robertson. Published by CRC Press. 2017.

Forest Management and Planning (2nd Edition) by Peter Bettinger, Kevin Boston, Jacek P. Siry and Donald L. Grebner. Published by Academic Press. 2017.

Forest Mensuration (5th revised edition) by Jack A. Kershaw Jnr., Mark J. Ducey, Thomas W. Beers and Bertram Husch. Published by Wiley Blackwell. 2016.

Keeping New Zealand Green: Our Forests and Their Future by Elizabeth L. Orr. Published by Steele Roberts Aotearoa. 2017

King Sequoia: The Tree that Inspired a Nation, Created Our National Park System and Changed the Way We Think About Nature by William C. Tweed. Published by Heydey. 2016.

* **Management Guidelines for Ireland's Native Woodlands** by John R. Cross and Kevin D. Collins. Published jointly by the Forest Service, Department of Agriculture, Food and the Marine and the National Parks and Wildlife Service, Department of Culture, Heritage and the Gaeltacht. 2017.

* **Manual of Tree Statics and Tree Inspection** by Lother Wessolly and Martin Erb. Published by Patzer Verlag. 2016.

Mixed Species Forests: Ecology and Management by Hans Pretzsch. Published by Springer. 2017.

My Wood by Stephen Dalton. Published by Merlin Unwin Books. 2017.

* **Nature's Temples – The Complex World of Old-Growth Forests** by Joan Maloof. Published by Timber Press. 2016.

Pro Silva Silviculture: Guidelines and Continuous Cover Forestry/Close to Nature Forestry Management Practices by Christine Sanchez. Translated from the original French and published by Pro Silva Ireland. 2017. Published by Pucci Publishing. 2017.

Remarkable Trees of South Africa (new edition) by Neels Esterhuyse, Jutta von Breitenbach, Hermien Sohnge and Izak van der Merwe. Published by Briza Publications. 2017.

Sacred Trees by Nathaniel Altman. Published by Gaupo Publishing. 2017.

* **Street trees in Britain** by M. Johnston. Published by Windgather Press. 2017.

* **The Hidden Life of Trees – What They Feel and How They Communicate** by Peter Wohlleben. Published by Greystone Books. 2016

The Living Forest: A Visual Journey into the Heart of the Woods by Robert Llewellyn and Joan Maloof. Published by Timber Press. 2017.

The Magic of Trees: A Guide to Their Secret Wisdom and Metaphysical Properties by Tess Whitehurst. Published by Llewellyn Publications. 2017.

* **The Man Who Made Things Out of Trees** by Robert Penn. Published by Penguin Books. 2016

* **The Sacred Trees of Ireland** by A.G. Lucas. Republished (original in 1963) by the Society of Irish Foresters. 2017.

The Tree Climber's Guide by Jack Cooke. Published by HarperCollins. 2017.

* **The Urban Tree** by Duncan Goodwin. Published by Taylor and Francis. 2017.

The World's Urban Forests: History, Composition, Design, Function and Management by Joe R. McBride. Published by Springer. 2017.

Totara: A Natural and Cultural History by Philip Simpson. Published by Auckland University Press. 2017.

Trees by Irene Kung and Giovanna Calvenzi. Published by Contrasto. 2016.

Trees in England: Management and Disease since 1600 by Tom Williamson, Gerry Barnes and Toby Pillatt. Published by University of Hertfordshire Press. November 2017.

Trees in Paradise: The Botanical Conquest of California by Jared Farmer. Published by Heyday. Reprint edition from original in 2013 (March 2017).

* **Trees in Towns and Cities: A history of British Urban Arboriculture** by M. Johnston. Published by Windgather Press. 2015.

White Pine: American History and the Tree that Made a Nation by Andrew Vietze. Published by Rowman and Littlefield. 2017.

Wise Trees by Diane Cook, Len Jenshel and Verlyn Klinkenborg. Published by Abrams. 2017.

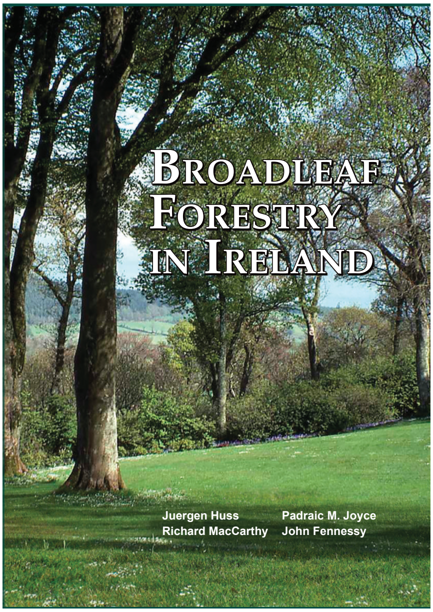
Wood by William Hall. Published by Phaidon Press. 2017.

Woodland and Forests: Explore Nature with Fun Facts and Activities by Jamie Ambrose, David Burnie and Linda Gamlin. Published by Dorling Kindersley. March 2017.

Woods: A Celebration by Robert Penn. Published by National Trust U.K. 2017.

Broadleaf Forestry in Ireland

Juergen Huss, Padraic M. Joyce, Richard MacCarthy
and John Fennessy
COFORD. 2016
508 pages. Hardback. ISBN: 948-1-902696-77-5
€40



In 1998, COFORD issued an impressive book entitled, *Growing Broadleaves*. Since 1998, the area afforested with broadleaf trees and the diversity of species planted has increased greatly. There has been a corresponding increase in silviculture expertise relevant to the species planted. This book incorporates much of the experience gained as well as results, from research, which have emerged since 1998. As a result, it is much more extensive and more substantial in scope than *Growing Broadleaves*.

It is presented in two parts, consisting of nine chapters, and comes to almost five hundred pages. Part one focuses upon the silviculture and economics of broadleaf trees and stands while part two describes many attributes of the major and minor timber producing species normally encountered in Ireland. In addition, there is a glossary of terms, a bibliography, an index of tree species mentioned in the text and a general index.

The introductory chapter consists of historical overviews of the development of forestry in Ireland. It includes a detailed inventory of the broadleaf estate in the country at the present time. Data are presented according to species, age-class distribution and ownership. Chapter 2 consists of an extensive review of the climate and edaphic factors which largely determine species selection, tree growth and plantation development. It includes a series of very clear descriptions and many excellent plates which show the soil types and profiles deemed suitable for the growth of broadleaf trees in Ireland. Recommendations for species selection and site preparation accompany the soil description. All forestry practitioners should find this chapter interesting and informative, especially the guidelines for species selection and lowland and upland sites (Tables 2.4-3 and 2.4-4). The detail given in this chapter is exhaustive with a tendency towards repetition. In Chapter 3, the social, ecological and economic functions which broadleaf stands and individual trees serve are discussed. This presentation on the multiple non-timber benefits of broadleaves is somewhat over-elaborate and even tedious. There is also a section on the economics of broadleaf forestry. The impact of rotation length and the price of land upon the returns that may be expected is clearly expounded. The authors conclude that growing broadleaves on a small scale, even when producing logs of the highest quality and value, is not profitable without subventions. The calculations presented only include the value of the detailed presentation on the non-timber values of broadleaf trees; it is surprising that no attempt is made to include these values in the economic appraisal.

As the primary focus of the book is on silviculture, the most important part is Chapter 4, however, it is also the longest (158 pages). All of the main operations relating to the establishment, tending and management of broadleaf trees are detailed. Topics discussed include: seed procurement, planting materials, site preparation, planting density, the aftercare of young stands, and formative shaping, pruning and thinning. Each subject is appropriately illustrated and recommendations for best practice are given. There is a lengthy discourse on mixed species stands and on the approach to thinning in such areas. The identification and favouring of potential crop trees at an early stage in the rotation is emphasised; this is deemed to be essential for the production of logs of the highest quality and value. Much of this discussion and stand treatment is neatly synopsised in two narrative-type tables (4.5-6, 4.5-7). There is also a long presentation on a range of silvicultural systems which may be appropriate for the integration of procedures in the management of broadleaf stands and forest. However, in view of the limited opportunities for the implementation of these systems, this lengthy discourse might have been more rigorously edited. The best chapter in part one of the book is the shortest. In it, the training and research needs for the future management of broadleaf trees and stands are indicated. The authors conclude that skills training and field demonstrations should form a part of any development programme.

Part two of this book consists of four chapters of varying length and significance. The content is, in most respects, quite different from that of part one. Despite this, it integrates smoothly into the general presentation of broadleaf trees. The main theme of Chapter 6 is an outline of systems for the classification of broadleaves. Seven systems are listed, but none of these is given in any detail. This lack of detail is in sharp contrast with most of part one. Indeed, Chapter 6 appears to be largely peripheral to the main themes of the book and this content adds very little to the knowledge of broadleaf trees. On the other hand, Chapter 7 consists of a cornucopia of detail on the natural distribution, botanical features, silvicultural management, growth characteristics, and wood properties of the broadleaf species of significance in Irish forestry. There are also comments on the silvicultural, economic, ecological and aesthetic values of each species. The distinguishing features of land, twig and leaf are given for most species. The entire chapter is again superbly illustrated however, the inclusion of species such as Italian alder, mana ash, Holm oak and black cherry appears to be an anachronism.

Chapter 8 follows the same pattern but as it deals with the so-called minor species, the descriptions given are less detailed. Most of the species included, such as rowan, horse-chestnut, holly and hawthorn are better known for their ecological and aesthetic values than for their timber production. The final chapter gives a brief account of some species which are not found in Ireland. It is noted that some individuals of these species have attained the status of "champion trees".

Technically, this is a superb book. The design, layout and printing are of the highest order and the text is enhanced by over 450 figures, plates and tables. The colour, clarity and relevance of the plates are excellent throughout. They do much to reinforce recommendations concerning species selection, natural regeneration, the management of mixtures of tree species, and practices associated with silvicultural systems. In addition, the manner in which recommendations and conclusions are highlighted in summary charts is helpful to the reader.

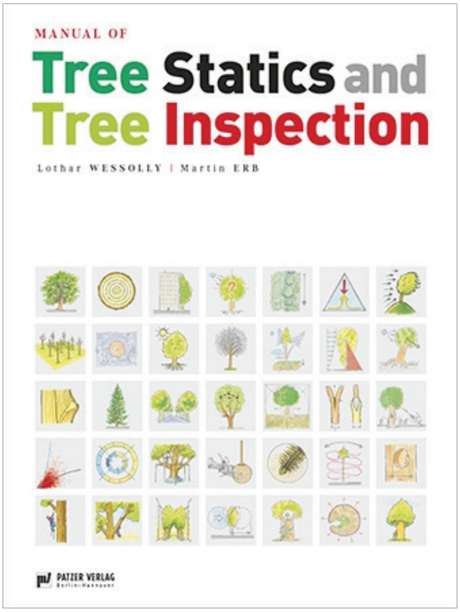
The entire book is a treasury of facts, figures and guidelines relating to broadleaf trees and stands. Despite this however, this book is not without its flaws. There is a strong element of repetition in selections and soils and on the non-timber values of broadleaf trees. The value of hedgerow timber is scarcely touched upon and no suggestions are included for the management of hedgerows or for upgrading the quality of the timber produced therein. Additionally, there is no mention of shelterbelts or agroforestry systems for timber production.

But the principal deficiencies of the book are editorial in character. As is to be expected in a book which has a number of authors, the style and quality of expression lacks consistency. There are instances of poor or clumsy sentence construction in virtually every chapter, e.g. "It has sometimes been argued that the potential to grow high quality timber is more difficult in Ireland when compared with conditions on the continent." In addition, tenses are often mixed, even in a single paragraph. There is considerable circumlocution and a drift towards tautology in sections of the book. There are also some very assertive statements with which this reviewer would find it difficult to agree, e.g. "All human activities - including forestry activities must adhere to an economic rational." It must be emphasised, however, that enquirers such as agriculturalists, landscape architects and environmentalists should find it an indispensable source of information; growers, too, would gain considerable direction from reading sections of this book, as would everyone involved in urban or rural planning. Generally, it is not a book for casual or recreational perusal; rather, it is a book which requires careful reading and study. Since no other publication on the management of broadleaf trees provides such a comprehensive exposition on this subject, this reviewer considers that it constitutes a standard reference. At a cost of €40 per hardback copy, it represents excellent value.

John J. Gardiner

Manual of Tree Statics and Tree Inspection

Lothar Wessolly and Martin Erb
Patzer Verlag: Berlin-Hannover. 2016
288 pages. Hardback. ISBN: 978-3-87617-143-2
€112



Perhaps some readers may find it surprising to see a title such as this reviewed in a forestry journal, but the ever-increasing overlap between traditional forestry and arboriculture justifies its inclusion. For example, the management of amenity woodlands is now covered in both forestry and arboricultural courses.

In this case it is worth listing the contents of this book. The sections include:

- The age of trees
- Tree biology
- Tree statics – statics and dynamics of the tree
- The diagnosis
- The detailed risk assessment
- Annexes and tables
- Bibliography
- Glossary and index

The book begins with a very succinct introduction followed by an extensive section on all aspects of tree biology. It is from this section that the forester will gain most from reading the book. Tree biology is explained with extensive use of coloured diagrams, as indeed are all sections of the book. In this regard, the book exhibits the same style of illustration as used by the famous German engineer and arboriculturist, Claus Mattheck.

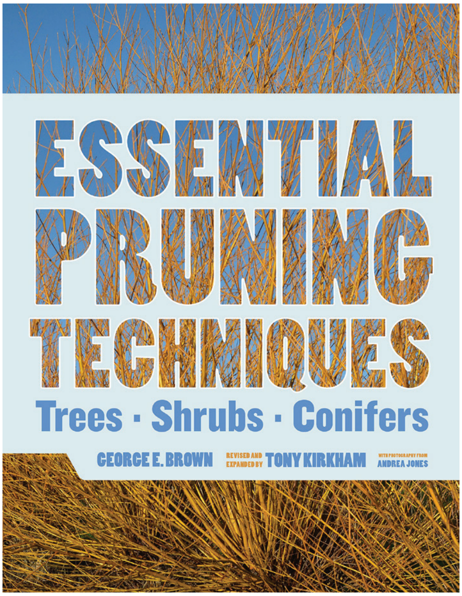
While most of the rest of the book deals with arboricultural principles and practices, such as those used in tree inspection, diagnosis and prescriptions, nevertheless it contains much of interest to the forester, particularly those involved in amenity woodland management and urban forest management. Examples would include selecting the tree species, selecting the tree in the nursery, quality control at delivery, time of planting, growing location and growing medium and all aspects of tree planting and aftercare. Pruning is also extensively dealt with.

Overall, this is an excellent book and highly recommended to those who consider it a worthwhile investment for study or professional use.

Kevin Hutchinson

Essential Pruning Techniques: Trees, Shrubs and Conifers

George E. Brown
Revised and expanded by Tony Kirkham
Photography by Andrea Jones
Timber Press. 2017
Hardback. 400 pages. ISBN: 9781604692884
£35.00



When George Brown's book *The pruning of Trees, Shrubs and Conifers* first came out in 1972, it quickly became a best seller and established itself as the standard reference on the subject. It has remained so for over 40 years.

Why a new version now? As the noted tree author, Hugh Johnson, says in his introduction to this book "Have trees changed? Isn't an oak still an oak?" Yes, but our knowledge moves on. Our expectations and tastes change. "The sum of professional experience grows." And who better to bring all of this together than Tony Kirkham, who is responsible for all the 14,000 trees and shrubs at the famous Kew Gardens. Based on his vast experience, Mr. Kirkham offers up-to-date pruning advice for 379 woody plants, step-by-step instructions on the latest techniques and practises, and specific advice for addressing risks from climate change.

The most obvious difference between this edition and its predecessors is the high quality photographic illustrations by Andrea Jones. To quote Hugh Johnson again "It is like walking through the ideal arboretum on a fine day".

This edition starts with a section on the general principles of pruning from tool selection and maintenance to such diverse subjects as fruit trees, hedging, pleaching, topiary etc.

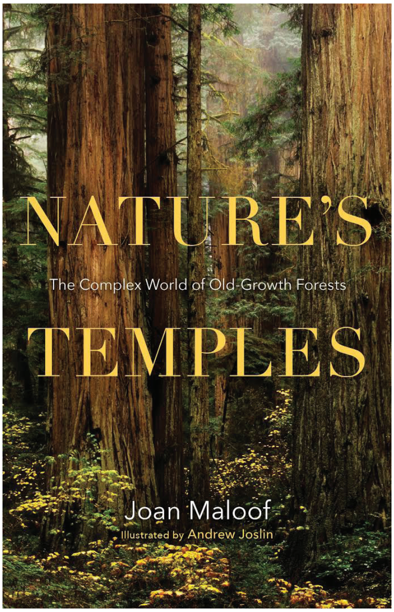
This book then takes the form of a gazetteer of woody plants from *Abelia* to *Zenobia* with plenty of discussion and advice on each. The author starts the section on each plant by answering the basic questions of "reasons for pruning" and "when to prune" – all basic, but very important information.

If you only ever have one book on pruning in your collection, let it be this one. Very highly recommended.

Kevin J. Hutchinson.

Nature's Temples – The Complex World of Old-Growth Forests

Joan Maloof
Timber Press. 2016
200 pages. Hardback. ISBN: 978-1-604-697285
€14.25



In this charmingly written and beautifully illustrated book, Maloof uses examples from the principal groups of organisms that occupy forests to illustrate the extent to which a vast range of species are dependent on old-growth forests.

The author defines an old-growth forest as one that has formed naturally over a long period of time with little or no disturbance from humankind. Such forests are increasingly rare and largely misunderstood. In *Nature's Temples*, Joan Maloof, Director of the Old-Growth Forest Network, makes a compelling and passionate case to underline their significance. An evocative and accessible narrative, it offers a rare insight into the many ways in which the life-forms (not just the majestic trees but also the insects, plant life, fungi, and mammals) in an ancient, undisturbed forest differ from the life-forms in a forest manipulated by humans. What emerges is a portrait of an intricate and fragile ecosystem that now exists only in scattered fragments. Black-and-white illustrations by Andrew Joslin help to clarify the scientific concepts and capture the beauty of ancient trees.

In this book the author eloquently urges us to cherish the wildness of what little old-growth woodlands we have left… not only are they home to the richest diversity of creatures, but they work hard on behalf of humans also.

Joan Maloof is a scientist, a writer, and the founder and Director of the Old-Growth Forest network, a not-for-profit organisation which aims to develop a network of forests across the U.S. that will remain forever unlogged and open to the public. Maloof studied plant science at the University of Delaware, environmental science at the University of Maryland Eastern Shore, and ecology at the University of Maryland College Park. She is the author of *Teaching the Trees* and *Among the Ancients*. Her conversational style will quickly dispel any lingering hesitation you might have about wading into the science of carbon sequestration or the life cycles of birds, amphibians, snails, insects, herbs, mosses, liverworts, trees, fungi, lichens, worms, or mammals. She puts each topic under the microscope and invites you to take a look and see the incredibly intricate world of old-growth forest ecology.

Maloof points out that "Forests are not just trees. Forests are complex communities. Trees anchor forests like corals anchor reef systems. You can't plant a coral reef system, and you can't plant an old-growth forest." Old-growth forests can, however, be easily destroyed. Joan Maloof knows this all too well and she delivers her message with the reverence appropriate to these upright "cathedrals of time". She combines an engaging writing style, scientific rigour and an advocate's skills to document the complex interactions of organisms that have evolved together in forests which have never been felled and replanted, in the process making a powerful case for treating pristine forests as sacred for people and wildlife.

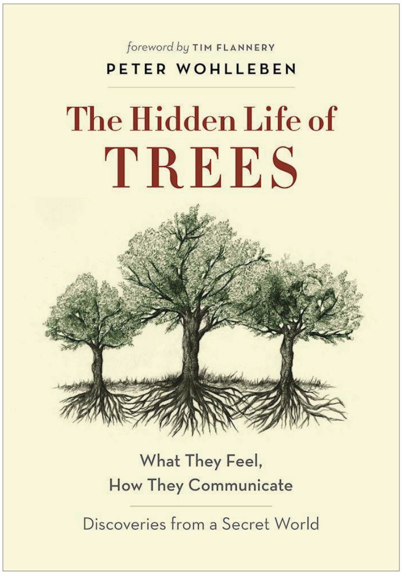
The author readily acknowledges that forest management and timber harvesting are important economically but contends that "most foresters agree that our remaining old growth forests should be preserved. They are living examples of how our forests behave when they are unmanaged". They also give us a base-line against which to compare how biodiversity changes when we manage forests. Preservation does not mean that the forest will always remain standing or always maintain the same species composition. Forests are constantly, if slowly, changing. Preservation means that we simply allow the forest to change at its own pace. Just because a forest was once destroyed – whether by humans or natural events – does not mean that it's unworthy of preservation.

Our nascent native woodland fraternity can learn much from this book. The author argues that old-growth remnants are now so rare that we should not be content with what little remains. We still have an opportunity to set aside second-growth forests (ones that were formerly logged and are now growing back) for recovery. These remnants – with our help – will become the seeds from which a renewed forest spreads. When we think of old growth we tend to think of western North America whereas we have our own semi-natural woodlands here in Ireland which also are worthy of preservation. Recent initiatives undertaken here have been very encouraging. *Management Guidelines for Ireland's Native Woodlands*, a recent publication which is reviewed elsewhere in this journal, will help to further advance the cause.

John Mc Loughlin

The Hidden Life of Trees – What They Feel and How They Communicate

Peter Wohlleben
Greystone Books. 2016
272 pages. Hardback. ISBN 978-1-77164-248-4
£16.99



Written by a German forester, this book recounts the lives of trees growing in a beech forest he manages near the town of Hümmel in western Germany. In it, Peter Wohlleben argues cogently that trees are sentient and that they "take care of their offspring and of each other". For many years he was a "regular" forester, as he says himself, planting and felling trees for lumber and as he points out, the commercial focus of his job warped how he looked at trees. However, as he moved through life he developed an interest on how trees communicate with each other. When he was a "regular" forester, "he knew as much about the hidden life of trees as a butcher knows about the emotional life of animals". Before you categorise him as a tree hugger, it should be pointed out that he quotes from a 1997 article in *Nature*, that most venerable of scientific journals, which unearthed the fact that there is a vast network of roots and fungi working together. In an appendix, Dr Suzanne Simard, a professor of forest ecology at the University of British Colombia in Vancouver, noted that where birches had been cleared in her trial plots, there was a decline in the growth of the Douglas firs. This research became known as the "wood wide web". One wonders, should we have allowed the birch to grow in our older Norway spruce plantations?

Of course, older foresters in Ireland are familiar with the reverse scenario, where it was extremely difficult to establish Sitka spruce on "heather" sites, particularly *Calluna vulgaris*. There is an incompatibility in the mycorrhiza of both species. The only option was to fertilise the spruce which allowed it to speed up growth and crowd out the heather.

It could be argued that the reason we tend to forget, or fail to recognise, how remarkable trees are could be due to our anthropocentrism as much as the fact that trees live their lives at a much slower pace but live for very much longer than we do. Wohlleben instances a small, gnarled spruce tree in northern Sweden which is estimated to be 9,550 years old – almost twice as old as the bristlecone pine in California.

The author also benefited from research carried out by the University of Aachen, the University of British Colombia and the Max Planck Society, which he claims underpins his vivid descriptions, but he writes as a conservationist and admits that much remains unknown. "It's very hard to find out what trees are communicating when they feel well," he says. "I don't hug trees and I don't talk to them." He goes on to say, "The thing that surprised me most is how social trees are. I stumbled over an old stump one day and saw that it was still living although it was 400 or 500 years old and without a single green leaf. Every living being needs nutrition, so the only rational explanation was that the tree stump was supported by the neighbouring trees, being fed via the roots with a sugar solution. As a forester, I learned that trees are competitors that struggle against each other, for light and for space, and there I saw that it's just vice versa. Trees are very interested in keeping every member of this community alive."

Beeches and oaks form forests that endure for thousands of years because they act like families, he says. Trees are tribal ('They are genetically as far away from each other as you and a goldfish') and ruthlessly protect their own kind; "Beeches harass new species such as oak to such an extent that they weaken." Douglas fir and spruce also bond within their species.

On the other hand, willows are loners. "The seeds fly far away from other trees, many kilometres. The trees grow fast and don't live very long. They are always the first, then they can't breathe any more after 100 years and then they are gone." Poplars aren't social either and "a birch will supress other trees so it has more space for its own crown. That doesn't sound very nice but I think birch has no other choice because that's what it's grown like because of its genes." City trees are like street kids – isolated, struggling against the odds and lacking strong roots.

One day, while in the forest, Wohlleben made an astonishing discovery: "The stones were an unusual shape: they were gently curved with hollowed-out areas.

Carefully, I lifted the moss on one of the stones. What I found underneath was tree bark. So, these were not stones, after all, but old wood. I was surprised at how hard the 'stone' was, because it usually takes only a few years for beech-wood lying on damp ground to decompose. But what surprised me most was that I couldn't lift the wood. It was obviously attached to the ground in some way. I took out my pocketknife and carefully scraped away some of the bark until I got down to a greenish layer. Green? This colour is found only in chlorophyll, which makes new leaves green; reserves of chlorophyll are also stored in the trunks of living trees. That could mean only one thing: this piece of wood was still alive! I suddenly noticed that the remaining 'stones' formed a distinct pattern: they were arranged in a circle with a diameter of about 5 feet. What I had stumbled upon were the gnarled remains of an enormous ancient tree stump. All that was left were vestiges of the outermost edge. The interior had completely rotted into humus long ago – a clear indication that the tree must have been felled at least four or five hundred years earlier."

How can a tree which was cut down centuries ago still be alive? Without leaves, a tree is unable to photosynthesise, which is how it converts sunlight into sugar for sustenance. This ancient tree was clearly receiving nutrients in some other way – for hundreds of years.

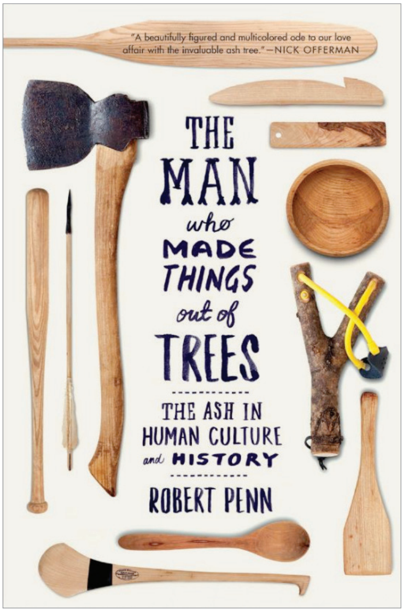
Beneath this mystery lay an intriguing new frontier of scientific research, which would eventually reveal that this tree was not unique in its assisted living. Neighbouring trees, scientists discovered, help each other through their root systems – either directly, by intertwining their roots, or indirectly, by growing fungal networks around the roots that serve as a sort of extended nervous system connecting separate trees. If this weren't remarkable enough, these arboreal empathies are even more complex – trees appear able to distinguish their own roots from those of other species and even of their own relatives. How are trees able to detect threats; for instance, how does the holly know that it should grow thorns on its lower leaves and none above the browsing line?

This fascinating book was translated from German by Jane Billinghurst, although the publisher fails to acknowledge this. For the record, Peter Wohlleben's book was a bestseller in Germany – it comfortably out-sold the memoirs of fellow Germans, Joseph Ratzinger (Pope Benedict) and Helmut Schmidt (former German Chancellor). Well now, there's a challenge for Irish foresters!

John Mc Loughlin

The Man Who Made Things Out of Trees

Robert Penn
Penguin Books. 2016
241 pages. Paperback. ISBN 978-0-141-97751-5
£8.99



Penn, born on the Isle of Man in 1967, says he grew up "under the influence of an ash tree" for there was one at the gate leading from his childhood garden to the fields beyond, where he and his brother played out their fantasies as children. He now lives in a small wood on the edge of the Black Mountains in south Wales.

Before he embarked on writing this book, Robert Penn cut down an ash tree to see how many things could be made from a single tree. After all, he says "ash is the tree we have made the greatest and most varied use of over the course of human history". Journeying from Wales, across Europe and Ireland, to the USA, Robert finds that the ancient skills and knowledge of the properties of ash, which were developed over millennia making wheels and arrows, furniture and baseball bats, are far from dead. The book chronicles how the urge to understand and appreciate trees still runs through us all "like grain through wood".

This book was originally published in 2015 by the Particular Book's Company and it is a testimony to its success that it's now being published by Penguin

Books. One can only speculate if the publicity surrounding ash die back disease was a factor in its rejuvenation. The author, who developed a love of ash as a child, predicts that all the ash on these islands will have disappeared in 50 years' time. In the meantime, the pathogen that causes ash dieback has been renamed *Hymenoscyphus fraxineus* (previously known as *Chalara fraxinea*). Hopefully his prognosis is unduly pessimistic as many of the predictions are based on the demise of elm which was largely clonal and thus lacked the genetic diversity of ash. Potentially more damaging to the survival of ash is the emerald ash borer, a beetle that has wreaked havoc on American ash populations and is now beginning to do the same in the UK.

Penn visited Ireland in 2013 and attended the epic All Ireland Hurling Semi Final match between Cork and Dublin. He found the game electric from the throw in and while in Ireland he visited hurley makers and marvelled at their craftmanship.

He lists the many items made from a single ash tree – desk, toboggan, six axe handles, six maul handles, ten spatulas, canoe paddle, coffee table, chair, two landing net frames, ten three-legged stools, charcoal, and a meat chopping board. The frame of a coracle was also crafted and the list goes on. Even then, it had more to give, including parts of the roof of a 16-foot yurt, a portable, round tent, porridge spoons and bowls, coat hooks, animal bedding, and kindling.

Then there were the felloes (for younger readers, felloes were the outer rim of a wooden cart wheel; they were usually made of ash, the spokes of oak and the central box which housed the axel was of elm). There are plenty of other delightful words from the woodworking lexicon that sound as reliable as the sturdy wood itself: a flitch (a stack of boards cut from the same log), quarrels (a crossbow's projectile), a bloomery (a furnace for roasting iron ore) and fiddleback (a decorative feature in maple wood). In all, he managed to make 44 items from that one tree. Penn doesn't go into the details of every item, but the items he chooses to highlight give the story impetus and energy, and readers are sure to come away with a greater appreciation of trees and of the artisans who craft with wood. Penn spends time with many resolute craftsmen, collecting words and the beautiful products they create for him, but also eloquently making the case for wood as a sustainable material not just of the past, but for the future. Penn says that "part of the attraction of ash is that it was always workman's timber, in contrast to the oak beloved of the aristocracy". Many people believe that the ash should be Ireland's National Tree rather than the sessile oak.

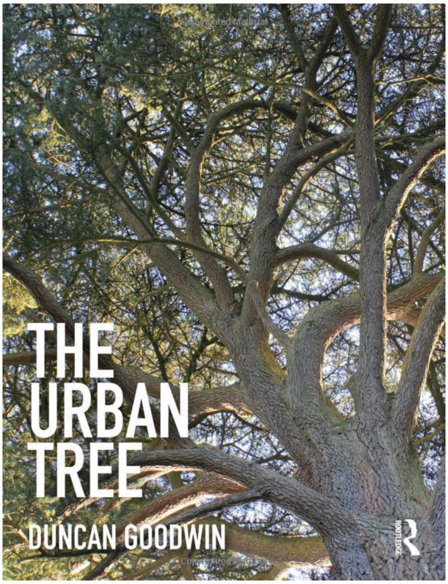
This enthusiastic tale of nature, human ingenuity and the pleasure of making things by hand records how the urge to understand and appreciate trees still runs deeply through us all like "grain through wood".

Robert Penn is an author, journalist and TV presenter. Robert wrote and presented Tales from the Wild Wood, a TV series about British woodlands. In 2011 he wrote *It's all about the Bike – The Pursuit of Happiness on Two Wheels*, which has since been translated into thirteen languages. He writes for the Financial Times, Observer and Condé Nast Traveller, as well as a host of cycling publications.

John Mc Loughlin

The Urban Tree

Duncan Goodwin
Routledge. 2017
265 pages. Hardback. ISBN 978-0-415-70246-1
£45.99



All tree species can trace their origins to a forest somewhere on the planet. However, nowadays many millions of trees are raised in specialised nurseries and spend their lives in cities where they provide a whole range of ecosystem services to urban dwellers. These include landscape, aesthetics, shelter, shade, pollution control, water filtration, wildlife habitats, noise abatement, climate change mitigation etc. All of these attributes were never more important than now given the pace of population change from rural to urban. In his introduction to Chapter One the author states:

> In 2008 the planet reached an important milestone. The world population moved from being predominantly rural to becoming mainly urban (UN Department of Economic and Social Affairs, Population Division 2008). This trend is set to intensify, and it is predicted that by 2050, two thirds of the world's population will be city dwelling (UN Department of Economic and Social Affairs, Population Division 2014).

It is entirely appropriate therefore that the urban tree is receiving more attention than heretofore in published textbooks. This volume is very welcome in that context.

In it the author draws on his vast experience in the variety of roles in which he has worked. It combines science and practice very well.

Chapters include:

- So, what have urban trees ever done for us?
- Tree structure and function – how do trees work?
- Urban soils and functional trees.
- Site assessment and analysis.
- Plant production. (This is a very useful chapter on a subject that does not always receive the attention it deserves.)
- Tree planting and establishment: technical design.
- Disorders, pests and diseases.
- Trees, regulations and law. (Irish readers should acquaint themselves with Irish law from other sources, several of which are available.)
- An integrated approach to green infrastructure.

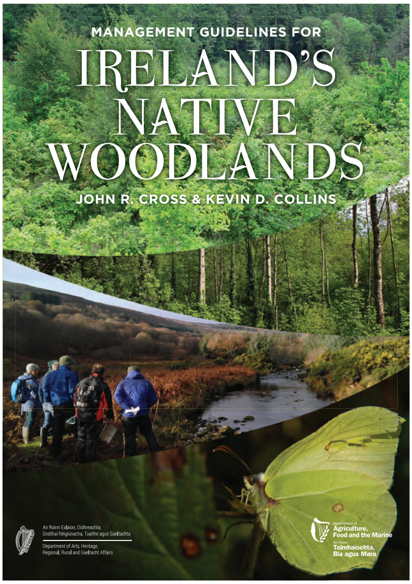
It also contains a useful set of appendices.

If your professional life involves looking after urban trees, then this a book for you. It is a wonderful combination of science and practical knowledge/experience and is recommended.

Kevin Hutchinson

Management Guidelines for Ireland's Native Woodlands

John R. Cross and Kevin D. Collins
Forest Service, Department of Agriculture, Food
and the Marine and
National Parks and Wildlife Service, Department of Culture,
Heritage and the Gaeltacht. 2017
Paperback. 146 pages. ISBN: 978-1-902696-78-2
Available free of charge from the Forest Service



In response to the renewed focus on Ireland's native woodlands, there are many publications which guide private and public native woodland owners towards a better understanding of the value of these woodlands and best practice in restoring them. This book compiles these guidelines and supports into a single, easily readable publication which dispenses practical guidelines on how best to manage, restore and hopefully, expand Ireland's native woodlands.

The opening section of the book presents an overview of Ireland's native woodlands, together with an introduction to the renewal of interest in restoring the "vital resource that is our native woodlands and the significant learning that ecologists and foresters have gained from working together and pooling their knowledge". The chapter entitled "Characteristics of Ireland's Native Woodlands" summarises their extent and distribution, the species which are found in the different woodland layers, the woodland type and age classification designations, woodland structure and woodland ownership. These topics are covered more comprehensively in Part B of the book - General Management Guidelines. The "Planning and Management" chapter is divided into national and site level planning plus a section on general management guidelines, while more detailed guidelines are found in Part B which are structured around 11 relevant topics, and in Part C around specific woodland types in Ireland.

I heartily welcome the promotion of Continuous Cover Forest (CCF) management systems throughout this book, in particular in the "planning and management" section. CCF systems are often viewed as complex, costly to implement and requiring intensive management. In my view, the opposite is the case. Once CCF concepts and silvicultural principles are understood, all that is then required is to have an inventory/monitoring protocol in place and ongoing selection and marking of thinnings on a regular cycle. A reference to an inventory/monitoring protocol is one element which I feel could have been added to the planning and management section because this informs the manager about how woodland structure (e.g. natural regeneration, shrub layer stocking, upper canopy structure, timber quality, deadwood quantity) and other ecological parameters are developing over time. This is particularly necessary in transformation/conversion from even-aged forest to an irregular multi-structured forest.

The requirement to have an overall objective for the native woodland is detailed clearly in the planning chapter. One of the objectives for each site will be to achieve the specified woodland type as outlined in the classification system most suited to that site. The planning guidelines in the manual outline the steps to be taken over time to achieve the selected objective or woodland type.

The first line of Chapter 11 - Products states "the overriding objective regarding native woodland is to manage for biodiversity and conservation". It also states that production of various wood products, using CCF, may be compatible with this primary objective. However, if we are to retain our native woodlands, I believe there must be a greater focus on making them economically viable. One of the primary drivers of the renewed interest and adoption of CCF across Europe has been the economic viability of this form of management. Of course, there are native woodlands where conservation and biodiversity should be the primary objective with minimal interventions to maintain the CCF system, but in general where CCF systems are adopted biodiversity enhancement and conservation go hand in hand with quality wood production and economic viability. The guiding principle in CCF management is to progressively concentrate stand production onto quality trees that can achieve premium prices e.g. the prices achieved for coopering quality oaks logs from Ballytobin Wood, Co. Kilkenny. Introducing an "A-D Quality Class Assessment" of the first 3-6 m lengths of trees at different stages of development to an inventory/

monitoring protocol incorporating financial appraisal and potential value would give great guidance to foresters in managing our native woodlands.

In Part B, the factors that one should consider when managing native woodlands are addressed via specific guidelines, the size of the woodland, the age or longevity of forest cover, the woodland structure, species and the achievement of natural regeneration are discussed together with specific guidelines on how best to enhance the native woodland characteristics. There is interesting discussion in the chapter on "Structure" on promoting irregularity in the vertical and horizontal structures within the different woodland types. The challenge for foresters is to achieve the transformation from the present even-aged single-story structure, which most of our native woodlands have, to a multi-storied irregularly structured forest. The extent of thinning and regeneration gaps is the kernel in the transformation thinnings which will lead, in time, to the irregular structure. A critical requirement for thinning interventions is the road/track network in the forest. This is mentioned in the chapter on Conversion, but I think it should also have been included in the planning section and given increased prominence throughout. The critical factor is that these are permanent tracks and machines should be confined to these tracks to minimise soil compaction and disturbance.

Pressures on native woodlands from grazing and invasive species are also addressed in Part B. These pressures can have significant cost implications in managing native woodlands and the management guidelines outlined in this manual give practical and pragmatic advice on addressing these threats. Grazing pressures are often put forward as a major obstacle to successful natural regeneration, especially where CCF is to be adopted. Grazing, especially by deer, is a threat to any form of management. Likewise, costs must be incurred in controlling Rhododendron, cherry laurel and other non-native, invasive tree species. Max Brucimacchie and Roland Suisse from Association Futaie Irrégulière, a group of French private forest managers formed in 1991 to promote the silviculture of irregular forest stands, recommended removal of prolific sycamore and beech natural regeneration in a pole stage native woodland in Curraghchase, Co. Limerick – such good practical advice is repeated in the book.

In the chapter on "Conversion" there is practical guidance on identifying opportunities for conversion of existing non-native woodlands to native species woodlands, either through transformation utilising CCF systems or by felling and replanting. The management guidelines sections provide valuable advice on which route to adopt.

In Part C there are excellent overall descriptions, characteristic features and specific management guidelines for eight different woodland types. A good knowledge of these will give guidance to managers in planning and managing many other woodland types. It was particularly interesting to come across the sections on hazel, willow and yew woodland and the guidelines for these woodland types, as the focus is generally more about the main oak, ash, alder and birch woodland types. The use of Scots pine as a nurse species is mentioned in the afforestation section, but I wonder if a Scots pine woodland type should also be adopted into our Native Woodland Types, given the recent research identifying native Scots pine populations at Rockforest near Corofin, Co. Clare. The publication concludes with four appendices; Appendix 2 is particularly interesting as it lists the various classifications of our native woodlands and links them in the table provided.

This book is enhanced by excellent photographs throughout which show all aspects of native woodland, from glue fungus to epiphytes to harvested, high quality coopering logs. It will serve as an excellent guide to foresters, ecologists and native woodland owners seeking to enhance, transform and manage native woodlands.

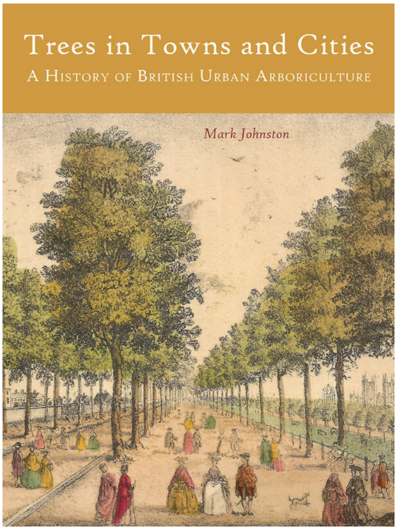
Padraig Ó Tuama is Secretary to the Executive Board of Pro Silva Europe.

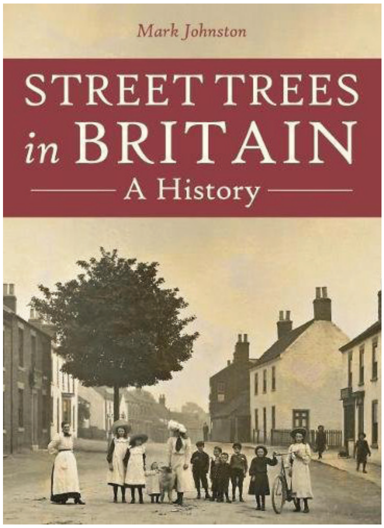
Trees in Towns and Cities: A History of British Urban Arboriculture

Mark Johnston
Published by Windgather Press, 2015
Paperback. 256 pages
ISBN: 9781909686625
£39.95

Street Trees in Britain: A History

Mark Johnston
Published by Windgather Press, 2017
Paperback. 352 pages
ISBN: 9781911188230
£29.95





These pioneering titles on the history of trees in British towns and cities walk one through the evolution of styles, trends and planting methods, as well as the care and use of trees in creating British urban landscapes. Though there are numerous books on the history of urban parks and open spaces, few focus on trees planted within them, nor do they address the subject of street trees and urban arboriculture. The author perceived a gap in the literature and delved deep into rare and old history books to gather information, illustrations and photographs to produce these two titles. The content within most chapters is described chronologically with some topics beginning in the Roman era however, there is a distinct focus on the Victorian and Edwardian periods. Progression through the chapters highlights major historical events that have changed and shaped the urban landscapes of today and people's attitudes towards them.

The author of these titles, Mark Johnston, has over forty years practical and academic experience in the urban greenspace industry. Initially working as a tree surgeon, Mark began to gather qualifications and a local authority tree officer position beckoned. This led to private consultancy, government advisory and university lecturing roles. This eclectic range of experiences and achievements puts the author in good stead to pronounce with considerable authority on these subject areas.

The first title, *Trees and Towns in Cities*, opens with a chapter that offers a much needed foundation in describing the origin and evolution of professional arboriculture. It explains how arboriculture is a relatively new concept that only in recent decades has managed to separate from its derivative origins in horticulture and forestry. European and American influences on the development of British arboriculture, the prominent individuals involved, and the founding of tree councils and societies are also discussed. This chapter prepares the reader for repeated reference to elements of forestry and horticultural practice that frequently appear throughout both books.

With past experiences in urban street tree maintenance, the standout chapters for this reviewer were those with a more practical element that dealt with subjects such as threats to urban trees, planting designs and the maintenance and management of street trees. Chapters describing threats to urban trees give interesting descriptions of conflicts between tree care and the development of urban environment through time. The overarching threat, from which all others stem, is the pressure from urban expansion. The author explains how increasing populations inherently result in competition for space, be that for development, infrastructure and services or for access. With each competitive factor comes a related pressure (literally) on the soil resulting in root zone compaction or pollution. These pressures are described in detail giving examples of the development of industrial towns and cities, their negative effect on the urban landscape and how some of these issues were resolved.

Topics such as disease outbreaks and war are also extensively considered in both books with descriptions of both positive and negative effects on urban greening. The Black Death in Britain caused a sudden decline in human population and an increase in naturally colonised tree populations in derelict sites. By the time the human population within the cities had recovered many of these trees were mature enough to force development to work around them and thus dramatically shaped the layout of many towns seen today. War had an opposite and negative effect on urban trees, particularly during World War II. The extensive bombing of southern British towns and cities was focused on parks and open spaces where defence forces based themselves for an unobstructed view of the skies. Inevitably, many trees in these parks were damaged or destroyed and due to the economic strain on resources at the time, these trees were not replaced or maintained. This issue of funding, or the lack of it, for urban greening purposes is a common theme in multiple chapters.

The second title, *Street Trees in Britain: A History*, is not a continuation of the first and is quite separate in its subject matter. Some topics are covered again, but the author's awareness of this is evident as repetition is kept to a minimum and only for context. The third chapter, Remnants from Past Landscapes, offers an interesting and somewhat heart-warming section on individual trees and their heritage value. It describes the historical and cultural significance of prominent stand-alone trees, how over time they have been adversely affected by urban development and the efforts that were made to retain them. Only eight individual trees are discussed in this section with approximate planting dates, their management and maintenance time and, for most, their inevitable demise. Johnston traces the remnants of some of these individual tree characters, some subtle and some distinctly less so, and examines their marks on local history, traditions and landmarks, e.g. where local businesses use the name of a tree or local festivities are centred around the remains of a tree. For example, the Mayoral gavel of the Town Council of Bexhill-on-Sea is carved from timber of the Old Walnut Tree which once proudly stood in the centre of a major road junction at the seaside town.

There is also tremendous comedic value to be enjoyed in both these titles, as seen through the article extracts from publications such as *The Garden* and *The Gardeners' Chronicle*. Authors of these articles expressed contravening views to the practices of the time by their use of colourful and inordinate language, thereby throwing caution to the wind and braving backlash responses. They would regularly call out local authorities on what they regarded as poor management practices, or fellow authors on loose recommendations, and in a style that the risk-adverse society of today would prefer to avoid. Phrases such as "…simply ludicrous" and "…not one iota of knowledge" are examples of some of the language that had this reviewer quietly chuckling. Unfortunately, many of these criticisms were directed at practices that are still evident in urban landscapes of today. Poor decisions in planning, tree selection, maintenance and, in extreme cases, tree removal can frequently be recognised in many Irish towns and cities. It seems that we may still have much to learn from the mistakes of the past.

The detail into which some topics delve may be of more interest to individuals working in local authority planning or as tree officers. Countless hours of research by the author is evident in the extensive reference lists following each chapter, which could point the interested reader towards further publications to improve their prowess. With this said, these two titles are most certainly not exclusively aimed at the professional audience. They are well written, presented, at times comical books, packed with interesting illustrations and photographs that make for easy reading by a wide audience.

Damien Maher

The Sacred Trees of Ireland

A.T. Lucas
The Society of Irish Foresters, 2017
56 pages. Paper back. ISBN: 978-1-78808-864-0
€10 (incl. P&P)

This reprint in book form of a seminal article first published in 1963 is very welcome. The author, Anthony Lucas (1911-1986), started his career as a primary-school teacher and studied for a BA and MA at night in UCD. He joined the staff of the National Museum of Ireland in 1946 and worked in the Folklife Division before becoming Director in 1954. In many ways he straddled the disciplines of archaeology, history and folklife and combined all three to bring added value to his published work. He was a very thorough researcher and combed through a great number of published historical sources from cover to cover collecting references (on index cards) to many aspects of Irish life that he was interested in. Much of this research appeared in an impressive output of publications, a full list of which, up to 1975, was compiled by Professor Etienne Rynne and has been included in this book. This shows the range of Lucas's research on many aspects of everyday life in the past from food to clothing to farming practices to many types of objects made of timber. The latter included sieves, horizontal mills, dugout canoes (now called log boats) and block-wheel cars. Of particular interest to the members of the Society of Irish Foresters would be his important book on furze: *Furze: a Survey and History of its Uses in Ireland* (Dublin 1960).

Lucas's text on sacred trees deals with the subject under a number of headings beginning with legendary trees mentioned in early Irish literature, then moving on to trees associated with churches and saints as mentioned in early sources and finally bringing the story up to the present day with rag bushes and trees at holy wells. The information is expertly contextualised and many references to such trees in all parts of Ireland are gathered together. It was not intended to be an exhaustive list, which the author clarifies clearly at the beginning. That said he did gather an extraordinary amount of information on the subject, especially from the early sources and his text has been and will continue to be an essential starting point for anyone carrying out research into sacred trees in Ireland.

One of the words for a sacred tree in ancient Ireland was *bile* and this element can be found in many place names such as *Ráith bileach* (Rathvilly, Co. Carlow, where my mother came from) and *Dún bile* (Dunbell, Co. Kilkenny, where I grew up). There were five great legendary trees in ancient Ireland, one of which was called *Bile Tortan*, at or near Ardbraccan, Co. Meath. It is said to have fallen in AD 600. Another was *Eó Mugna*, which Lucas correctly associates with Ballaghmoon (*Bealach Mugna*), Co. Kildare. The adjoining parish to the north, with its ancient church, is called Dunmanoge, the old form of which was *Mugna Moshenóc*. There is no doubt but that *Eó Mugna* was located in this area of Co. Kildare possibly in or around Dunmanoge and that Ballaghmoon gets its name from a roadway that led to or past *Mugna*. A more recent author on sacred trees, C. Zucchelli (*Trees of Inspiration*, Cork 2009, xvi), claimed that there was great uncertainty about the location of this tree mentioning two possibilities: Moone, Co. Kildare and Ballaghmoon, Co. Carlow, both of which are wrong. While there is no townland called Ballaghmoon in Co. Carlow, there is one with a remarkable castle called Ballymoon, which some writers have mistakenly identified with *Bealach Mugna*.

Sacred trees or sacred groves marked many pre-Christian sanctuaries and assembly places in Ireland, as indeed in other countries, and a number of places where Irish kings or chiefs were inaugurated had such a tree or trees. On occasion these became a target for an enemy and there are a number of references in the Irish Annals to enemy raids when sacred trees at inauguration places such as Magh Adhair (that of the O'Briens in Co. Clare) and Tullaghoge (that of the O'Neills in Co. Tyrone) were deliberately cut down.

With the arrival of Christianity, the church adopted aspects of the old religion and sacred trees are recorded at church sites and associated with saints. For example, Lucas documented references to three sacred trees at Clonmacnoise: an elm mentioned in the Calendar of Oengus; an oak that fell in AD 1013 and the yew tree of Ciarán, which was struck by lightning in 1149, killing 113 sheep that were sheltering under it. A reference that can be added to those mentioned by Lucas is to two trees at Armagh that are referred to under the year 1165 in *Miscellaneous Irish Annals* (Dublin 1947): *Dair Colaim Cille* and *Craobh Brighde*.

In documenting sacred trees at holy wells and other named trees he makes good use of more recent folklore and nineteenth-century sources such as the Ordnance Survey Letters. One that can be added is the tree at the holy well at Mullennakill, Co. Kilkenny, an example that is in Zucchelli's book. This was cut to the butt with a chain saw a few years ago, but hopefully it has sprouted again like the better-known St. Fintan's Tree at Clonenagh, Co. Laois. The latter tree, a sycamore, fell some years ago having been poisoned by the practice of pilgrims hammering money into its trunk. The Mullennakill tree, associated with St. Moling, has the distinction of being the subject of an eighteenth- or early nineteenth-century poem in Irish – *Tiobar deas Chrann Molaing* (D. Ó hÓgáin, *Duanaire Osraíoch*, Baile Átha Cliath 1980, 61).

The association of trees with funerals and burials, as documented by Lucas, brings to mind a suggestion I made many years ago. It concerned an Early Bronze Age burial monument, consisting of a penannular ditch of horseshoe plan, which was excavated at Shanaclogh, Co. Limerick. The excavator found evidence for the burnt-out root system of a tree in the gap between the terminals of the ditch and assumed that the tree was modern. I made the suggestion that the tree could have pre-dated the burial monument and that the ditch could have been dug forming a loop out from the tree with the tree completing the symbolic circle (C. Manning, A note on sacred trees, *Emania: Bulletin of the Navan Research Group* 5 (1988), 34-35). If this was the case it was surely a sacred tree. One of the references I used was, of course, Lucas's article.

This reprint has been published to mark the 75th anniversary of the founding of the Society of Irish Foresters and was certainly a most appropriate way of marking the occasion. This book was and remains a pioneering and indispensable study of the subject and I personally am very glad to have it in book form to replace the battered, annotated, stapled photocopy of it that I have held onto for over forty years. The book has been very stylishly produced with a beautiful cover image by Gerhardt Gallagher, a foreword by Gerry Murphy, President of the Society of Irish Foresters, an introduction, with much useful information about the author, by Hugh Crawford, President of County Kildare Archaeological Society, and an index.

Conleth Manning has recently retired as
Senior Archaeologist with the National Monuments Service.

Society of Irish Foresters Study Tour to Austria

11th–15th October 2016

On Tuesday, 11th October, forty-four members of the Society of Irish Foresters departed Dublin Airport to begin our 73rd annual study tour to Austria. It was the Society's first study tour to Austria.

Austria, a federal republic, is a landlocked country with a population of just over 8.7 million inhabitants. It is bordered by the Czech Republic and Germany to the north, Hungary and Slovakia to the east, Slovenia and Italy to the south, and Switzerland and Liechtenstein to the west. Austria has an area of 83,879 km^2; the island of Ireland is slightly larger at 84,421 km^2. Austria's terrain is extremely mountainous; only 32% of the country is below 500 m, and its highest point (Grossglockner) has an elevation of 3,798 m.

Almost half of Austria's land area is forested. Private forest owners, with less than 200 ha, make up 49% of the total forest area and private landowners with more than 200 ha make up 21%. Only 16% of the forests are owned by the state. The remaining forests are owned by community groups and the church. Interestingly, many Austrian monks are trained foresters.

Austria's forests are 75% coniferous. Norway spruce is undoubtedly the most important species comprising just over 60% of the forest area. Scots pine is next at 7%. The main broadleaved species is beech which comprises almost 10% of the forest area, followed by oak at 2%.

Our tour leader was Michael Bubna-Litic, Managing Director of PAN Forst who compiled an interesting and varied programme for our tour. A knowledgeable and entertaining guide, he was ever willing to share his deep knowledge of forestry in Austria – and not just forestry; he took great pride in educating us on all aspects of Austrian life, from architecture to wine growing. On the final day of the tour, he and his family entertained us lavishly at their estate for which we are most grateful. We were based in the town of Krems an der Donau, approximately 70 km west of Vienna, for the duration of the tour.

Overnight – Hotel Unter den Linden

Pat O'Sullivan

Day two: Wednesday, 12th October

On the first morning of the tour we travelled south from Krems, climbing gradually through scenic, forested valleys to the village of Nasswald (Figure 1). There we met our host for the day, Werner Fleck, who is in charge of forest management planning in the district, and Peter Lepkowicz, head of the District Forest Management Unit. One of five forest districts in Lower Austria, Nasswald covers an area of 44,000 ha comprising 33,000 ha of "water protection" forests, 8,500 ha of urban forests, and 2,500 ha of agricultural land.

The district's primary management objective is to protect the pristine spring waters which supply drinking water to the city of Vienna, 100 km to the north east. During the 19th century, the Austrian government purchased large tracts of land to secure the forests in the "water protection" zone. Nasswald's forest management regime is adapted to protect the quality of Vienna's drinking water. For example, in order to prevent sedimentation and erosion, clearfelling is not allowed; thinning is permitted but heavy extraction machinery cannot be used and extraction is mainly by skyline. The use of chemicals is totally forbidden. Up until the late 1950s, large scale clearfelling followed by replanting with pure spruce was the norm. However, these plantations are now being transformed into mixed species forests. Bark beetle is not a major problem in this area but where outbreaks did occur, the affected trees were debarked either manually or by machine. This district has a staff of four foresters, six hunters and 35 industrial workers who are mostly contractors.

Annual timber production in the Nasswald district is 19,000 m^3; 10% of the

Figure 1: *The forested mountains of Nasswald supply pristine spring water to Vienna's 1.8 million inhabitants.*

extraction is whole tree harvesting and 90% of assortments are made in the forest in order to leave the biomass on site. The district's revenue is derived from timber sales and an annual payment from the city of Vienna for protecting its drinking water supply. Residents in Vienna (1.8 million) pay €2 per m^3 for water. The underlying geology of the district is karst limestone. The main species of wildlife found in the forests are deer (red and roe) and chamois. There are also very small numbers of bears, lynx and wolves. Later we were shown some vintage forest machinery, including a Timberjack skidder which is no longer used for timber extraction as it caused too much soil damage. It is now used to anchor a cable extraction unit!

Our next stop was at a fish farm which is owned by the district. It produces 2,000 kg of fish annually and also supplies young fish for restocking streams. Close to the farm is a small abattoir which processes about 30% of the animals that are culled each year. It is planned to franchise this enterprise next year as direct labour costs are too high. Before lunch, we visited a small forest museum which had an interesting display of tools, clothing and photographs of forest operations from the 18th and 19th centuries. The museum featured a scale model of an ingenious system of transporting logs by water which foresters in the 19th century had devised, as the steep valleys were poorly roaded at the time. This was to meet the burgeoning demand for timber to satisfy the smelting industry and the huge firewood market in Vienna. These resourceful foresters had even bored a tunnel through a mountain in order to transport the timber from an inaccessible but heavily forested valley beyond.

After lunch, we travelled to the nearby Kaisebrunn Water Museum where we were introduced to Hans Tobler, general manager of the Kaiserbrunn waterworks (Figure 2). He showed a film on the history of supplying drinking water to Vienna from these alpine valleys. The original 102 km-long tunnel was completed in 1873 after four years of construction. As the city of Vienna expanded, a second, 194 km-long tunnel was built between 1900 and 1910. There are also some spring groundwater systems within 30 km of the city which are its third source of supply. No water filtration is needed in the Kaiserbrunn area because of the high quality and purity of the springs. Here, the water quality is constantly monitored and if a particular spring drops slightly below the quality threshold, the water from that spring is temporarily discharged into a local stream. The drinking water supplied to Vienna is stored in 30 reservoirs around the city which have a combined storage capacity of 1.8 million m^3. Hans Tobler explained that water is also pumped up to the high-altitude skiing lodges and that the sewage from those lodges is pumped 2 km downhill to treatment plants in order to ensure the purity of the spring waters. After a very long and interesting first day, we then travelled back to our hotel in Krems.

Overnight – Hotel Unter den Linden

Eugene Griffin

Figure 2: *The water quality monitoring station at Kaiserbrunn, Nasswald. The water collected from the mountain springs in this area is so pure that no filtration is required before it flows through 100 km of tunnels to the Austrian capital, Vienna.*

Day three: Thursday, 13th October

On Thursday morning, we headed north towards the town of Rastenfeld, accompanied by Michael Bubna-Litic, our leader for the remainder of the tour. On the journey to Rastenfeld we passed through prosperous farmland and fine vineyards. This is the main wine producing area of Austria and it is particularly well regarded for its white wines.

In this part of Lower Austria the impact of a warming climate is becoming noticeable and is beginning to impact on the forests. Annual rainfall has dropped to 400 mm and mean temperatures have increased by 3 ^{o}C over the past few years. These changes have already had an adverse effect on the health of the region's pine and spruce forests.

In Lower Austria, the forests are 16% state owned, 50% farmer owned and the remaining 34% is owned by a mix of large private estates, investors, forestry companies etc. The average forest size is 5.7 ha. The main species is Norway spruce (60%) while pine, birch, oak, and other minor species comprise the remaining 40%. The area's pine forests are starting to suffer badly from the effects of a drier climate and Douglas fir is being assessed as a replacement species for pine. Norway spruce is also under pressure from the spruce bark beetle as it is pre-disposed to attack by the debilitating impact of climate change. The average yield class of spruce is 10 $m^3 ha^{-1} yr^{-1}$, while the average yield class of pine is 6 $m^3 ha^{-1} yr^{-1}$.

Our first stop of the day was at a biomass power plant on the outskirts of the town of Rastenfeld. The complex comprises a sawmill and a wood pellet production plant with a combined heat and power (CHP) plant which is operated by Nawaro-Energie GmbH. The combined heat and power plant was the focus of our visit. Our host was Gunther Eggenberger and we also met with Hans Scherzen and Wilhelm Berger, who acted as guides and interpreters for our tour of the facility. The Nawaro-Energie CHP plant supplies power and steam to both the sawmill and the wood pellet mill and sells any excess power to the national grid. The plant has two 5 MW generators and an additional 2 MW energy equivalent is extracted as steam from the pellet plant and sawmill.

The chips for the mill are generally sourced within a 70-km radius of the plant, but when supply becomes scarce, chips can be imported from as far away as western Romania. There are four quality grades for chips; the top grade is chips from roundwood and the lowest grade of chips comes from branches and bark. Each grade has a different calorific value and ash content so they are mixed thoroughly in the yard before being fed into the furnace. As each truck enters the yard (Figure 3), its load is sampled at the weighbridge. The sample is dried and a dry tonne conversion and quality grade is then calculated for the load. On average, the mill pays €18 - €20 per m^3 of product delivered. The average moisture content of the delivered material is 37%. However, this ranges from 40% in the winter to 26% in the summer. The plant uses approximately 700 dry tonnes of material per week.

After a fine lunch at the Ottenstein Hotel near Rastenfeld, we headed further up into the hills to visit an IUFRO thinning experiment near the village of Döllersheim. This was the village where Adolf Hitler's paternal grandmother lived. However, after the 1938 annexation of Austria, Hitler ordered the evacuation and destruction of Döllersheim and surrounding villages to make way for a large Wehrmacht training camp.

Our next stop was at the IUFRO European Stem Number Experiment in Norway spruce (Figure 4). Our host was Thomas Ledermann from the Austrian Research and Training Centre at the Department of Forest Growth and Silviculture (BFW). The forest is privately owned but it is managed by BFW. This stop was particularly interesting for our Chairman, Dr. Gerhardt Gallagher, who was a member of the original IUFRO Working Party that established the research programme across 14 European countries in 1967. The trees on this site were planted in 1959 using three-year-old plants. The spacing was 1.3 m to 1.4 m resulting in 5,200 to 6,000 plants ha^{-1} after planting. Due to varying growth rates across the 14 European countries selected, top height was used to determine the time of thinnings. Accordingly, stocking was reduced to 2,500

Figure 3: *A truck load of steaming chips arrives at the Rastenfeld biomass power plant which is operated by Nawaro-Energie GmbH. As loads will vary in calorific value and ash content, the chips are mixed thoroughly in the yard before being fed into the furnace.*

stems ha^{-1} at a top height of 5 m. The longevity of the experiment led to discussion on the appropriateness of the old yield tables given the many changes in treatments since 1967 – a period of almost 50 years. In addition, there is the possibility of a vegetative impact on Norway spruce due to an increase in the length of the growing season as a result of climate change. Despite its age, researchers at BFW continue to acquire valuable information from this experiment, for example on the impact of climate change on species selection. The second discussion centered on the value of long term research and also the protection and storage of experimental results. This is a debate which is occurring in Austria and it is also one of great relevance in Irish forestry.

Our final stop was at a nursery - Landesforstgarten Ottenstein. Our host was Heinrich Anibas. The nursery area is 25 ha in extent and produces 1.25 million plants per annum; 50% of the plants are bare rooted and the remainder are potted. The nursery also produces semi standards (2 m tall) and standards for markets such as parks and motorway landscaping.

Overnight – Hotel Unter den Linden

Pacelli Breathnach

Figure 4: *Gerhardt Gallagher and Thomas Ledermann, research forester with the Austrian Research Centre for Forests (BFW) in the IUFRO thinning trial near Döllersheim. Dr. Gallagher was a member of the original IUFRO Working Party that established this research programme in 14 countries across Europe in 1967.*

Day four: Friday, 14th October

The group headed 60 km southwest from Krems an der Donau, following the Danube to the Stora Enso sawmill at Ybbs an der Donau (Figure 5). The mill, located on a 25-ha site at the confluence of the rivers Ybbs and Danube, is one of more than twenty Stora Enso production units in Europe.

Although Stora-Enso was formed as recently as 1998 when the Finnish company Enso Oyj merged with Stora Kopparbergs Bergslags Aktiebola, the company has a long tradition in forestry and mining going back to 1288. It eventually sold its mining operations to concentrate on forestry, pulp and paper in the 1970s. Today, Stora-Enso employs 27,000 people in 35 countries and has annual sales of €10 billion. The Ybbs plant was established in 1983 by Holzindustrie Schweighofer and was acquired by Stora Enso Wood Products in 1999. The annual intake of logs at the Ybbs plant reached one million m^3 in 2015. While the forests of Austria have a diverse range of species, this sawmill, like most Irish processing mills, relies mainly on spruce. In Austria, Norway spruce provides 90% of Stora's log supply with pine species forming the remainder.

Figure 5: *Society members receive comprehensive safety instructions before being taken on a guided tour of the Stora Enso sawmill at Ybbs an der Donau. Accident-free for more than 500 days, the mill is justifiably proud of its safety record.*

The mill at Ybbs produces 562,000 m^3 of sawn material, or a sawn recovery rate of 57%, which is an excellent return bearing in mind that 51-53% is normal for UK and Irish mills. The bulk of sawn timber is sold for construction and joinery, along with 58,000 m^3 of fencing material and 50,000 m^3 going into the fast expanding cross laminated timber (CLT) market. The CLT unit at Ybbs was set up 2011. In addition to sawn material, fencing posts, and CLT, they also produce high quality joinery timber. To meet burgeoning demand, Stora Enso built a third joinery plant on the site in 2015.

CLT is an engineered wood building system comprising layers of boards glued together under pressure with the grain of the boards in one layer running perpendicular to the grain in adjoining layers. It has high strength and dimensional stability and can be used with, or as an alternative to, concrete, masonry and steel in many building types (Figure 6). Austrian architects, engineers and builders are leaders in CLT construction but other countries are also well advanced. Buildings up to 50 m high have been constructed using CLT in Norway and Canada.

In Austria and elsewhere in Europe, Norway spruce is the preferred timber for CLT, although NUI Galway is conducting research trials exploring the suitability of Sitka spruce for CLT. Our guide points out the advantages of building in CLT as wooden houses need less heating than a brick or concrete building. “CLT provides nearly unlimited possibilities in architectural styles and construction," he said. "It has perfect compatibility with other building materials and can be used in exterior or interior walls, floors and roofs."

Stora places strong emphasis on renewable energy all the way through from design to construction. Most of the 43% mill residue is used as an energy source in its own mill and in products such as wood pellets which it also produces in the Ybbs plant. The Stora vision is: "Everything that's made with fossil-based material today can be made from a tree tomorrow." Replacing construction materials and fossil fuels with wood and wood products sounds like an extravagant boast. However, like the Austrian government and forestry stakeholders, Stora-Enso is committed to its corporate vision as Austria aims to become a totally green economy by 2050. With 41.6% of its land under forest cover, Austria is well positioned to maximise the use of wood in construction, design and energy.

The EU has set a goal of increasing the share of energy from renewable sources to 20% by 2020. While Ireland is unlikely to achieve 14% renewable energy, Austria had already reached 31% by 2010 and expects to achieve a level of 34% by 2020. In addition to hydropower, the most important renewable energy source in Austria is biomass, with a share of over 45% of the country's renewable energy programme.

Figure 6: *Demonstrating confidence in their product! Note the absence of any intermediate support structure on a CLT footbridge which spans a four-lane highway beside the Stora Enso sawmill at Ybbs an der Donau.*

In the afternoon, we drove north east for approximately 60 km to the forest and farm of our guide Michael Bubna-Litic and his family at Haitzendorf-Donaudoff. On the way, Michael spoke about the farmers and their interest in forestry, which is active throughout the forest cycle from planting to harvesting.

To describe Michael's approach to land and forest management as "biodiversity driven" tells only part of the story. "Our main objective, like past generations, is to secure the estate's forest stands for future generations," he said. "In achieving this goal, we have several departments including forestry, agriculture, viniculture, and nature protection as well as an engineering section to take care of harvesting and other work."

His estate (1,079,500 ha) employs a staff of seven and comprises the following land use categories:

- Forest - 943,365 ha
- Agriculture - 85,315 ha
- Vineyard - 7,502 ha
- Water area - 37,950 ha
- Other - 5,368 ha

The forest has 40 tree species comprising poplar (33%) – mainly hybrid, black and white – ash (13%), sessile oak (8%), beech (2%), maple (1%), robinia (2%), Scots pine (10%), larch (5%), Douglas fir (7%), Norway spruce (4%) and grand fir (3%), with 12% diverse conifers and broadleaves forming the remainder of the forest.

Michael Bubna-Litic, like Irish foresters, is also dealing with forest protection. For example, 15 years ago a beaver was marooned in a section of his forest, causing damage to 50 ha of woodland, mainly hybrid poplar. "Since beavers are a protected species, we had no choice but to accept the damage," he said. However, he believes that it is reasonable that his company "demands clear regulations, regarding the reduction of the beaver population".

His 122,600 ha of ash is also under threat from Chalara, ash dieback disease, caused by the fungus *Hymenoscyphus fraxineus*. As Irish foresters and forest owners search for a replacement for ash, Michael has a rich palette of broadleaves to select from. He is an enthusiast of black walnut because it produces a high quality, distinctive wood as well as edible walnuts which are cultivated for their desirable taste. Unfortunately, walnut is susceptible to canker disease which is causing a decline in walnut production in Austria. Income from game including deer (mainly roe but also fallow and sika) and wild boar provides a lucrative source of revenue for the estate.

He manages the forest in accordance with strict environmental, social and economic standards and is proud that this has been the case since the Bubna-Litic family acquired it through marriage in the early nineteenth century. These standards are higher than those required by certification bodies. In fact, he harbours a robust suspicion of certification schemes in general. He views such schemes as merely “money making ventures” which cause him much additional and unnecessary expense while delivering few benefits. He resents having to pay an annual subscription to certification bodies for adhering to standards which have been part and parcel of the Bubna-Litic estate management policy for generations.

Overnight – Hotel Unter den Linden

Donal Magner

Day five: Saturday, 15th October

We headed for Vienna and completed a tour of the city with our bus driver as a guide. We then headed south to Vienna International Airport to begin our journey home to Dublin.

Tour Participants

Pacelli Breathnach, Daniel Burns, Hugh Cawley, Brian Clifford, Philip Comer, John Connelly, Robert Dagg, Padraig Dolan, Declan Egan, Niall Farrelly, P.J. Fitzpatrick, Jerry Fleming, Gerhardt Gallagher, Tony Gallinagh, John Galvin, Seán Galvin, Eugene Griffin, Marcus Hanbidge, George Hipwell, Mark Hogan, Kevin Kenny, Gordon Knaggs, Daragh Little, Donal Magner, John Mc Loughlin, Aiden Maguire, Jim McHugh, Eugene McKenna, Willie McKenna, Padraig McMahon, Paul McMahon, Gerry Murphy, Liam Murphy, Frank Nugent, Benny O'Brien, Michael O'Brien, P.J. O’Callaghan, Kieran O’Connell, Owen O’Neill, Pat O’Sullivan, Martin Regan, Barry Rintoul, Richard Romer, Trevor Wilson.

Obituaries

Thomas Peter Damien (Tom) Hunt
1932–2016

On 21st November 2016 at St. Francis's Hospice, Blanchardstown, Tom Hunt passed away peacefully in his 85th year after a protracted illness which, as one would expect of the man, he bore with great fortitude.

Tom was born, the youngest of four siblings, on 25th February 1932 into a farming family at Corrigeenrore, Boyle, Co. Roscommon to Thomas and Mary (née Mc Loughlin). He received his primary education locally at Knockvicar National School and his secondary education at Summerhill College, Sligo. Like his siblings before him, Tom won a scholarship to attend this boarding college.

He began his forestry training at Avondale Forestry School, Co. Wicklow on 3rd January 1951. On completion of his studies, in September 1954, he was appointed as Assistant Forester to Head Forester, John Doyle, in Killarney, Co. Kerry. Later he was assigned to Mountrath, Co. Laois where he spent three years and from there he was transferred to Ballymahon, Co. Longford. In 1959, he was transferred again, this time to Co. Mayo where he was appointed a research forester with responsibility for organising the field-work to establish experimental forest plots and subsequent assessment of their performance. Tom was responsible for laying down the important peatland experiments at Glenamoy Forest, Co. Mayo.

Tom married Clare McNamara from Thurles, whom he met while in Mountrath, Co. Laois and they set up their first home (the first of 14 homes!) at Bangor Erris, Co. Mayo, later moving to Castlebar. In 1964, he was promoted as Forester Grade 2 and transferred to Tinahely Forest and Nursery in Co. Wicklow. In August 1969, he was promoted to the role of Forestry Inspector, Grade 3, and assigned to Avondale House – just in time for its reopening as Avondale Forestry Extension School.

Tom had purchased a house site some 10 miles from Avondale. However, the then Chief Inspector was so annoyed at this that he transferred him to the Wicklow District, whereupon he resided in Wicklow Town. The Chief Inspector was insistent that Tom should live closer to Avondale as he was concerned about the newly appointed young matron and her domestic staff, particularly since it was proposed to open a bar on the premises. It seems that he had expected Tom to act as a moral enforcer for the Department! In any case, fate intervened and the crisis was averted because the bar never opened. It is reported that the Establishment Officer (Human Resource Manager in today's parlance) was not too pleased when he noticed Tom distributing bottles of stout to forest workers on the day of the official opening. Tom was well aware of the Trojan work these men had done to ensure that the grounds of Avondale House were in pristine condition for the official opening and, being a fair-minded man, he felt they deserved some acknowledgement and recognition for their efforts.

In 1970, Tom was transferred to Sligo as a Method Study Inspector. Here, he worked with Benny Maloney (a former Coillte director and father of its current Chairman) who was then a Work Study Inspector. In 1978 he was promoted to the role of Forestry Inspector, Grade 2, and assigned to the Cork Division as Method Study Inspector. On reflection, one could scarcely conceive a more appropriate role for the man as he was most precise, diligent, meticulous and exacting in everything he did. In 1986, in his final career move, he was assigned to the Cork District as District Inspector. Tom availed of early retirement on 31st January 1991.

Tom was an intelligent, amiable, and most amenable forester who carried lightly his profound knowledge of scientific and practical forestry and nursery practice. He will be remembered by his many friends and colleagues as an outstanding forester and nursery manager and above all, a man of immense personal integrity.

Tom served on the executive committee of the State Foresters Association (SFA) for many years and also served as its Treasurer. He was a tireless worker in helping to improve the terms and conditions of his fellow foresters. This was no easy task at that time as the dead hand of Civil Service regulation often curbed the innovation and energy of Tom and his colleagues.

In the early days of his retirement he travelled abroad extensively. However, ill health curtailed his travels in later years. He was a very charitable man and devoted many years of his life to charitable causes. He was a marriage guidance counsellor for more than twenty years and was a member of the St. Vincent de Paul organisation. He treated all this work in a very confidential manner and very few knew of his involvement.

Throughout his career as a forester, Tom was a committed member of the Society of Irish Foresters and during his long association with the Society, he attended many events at home and abroad. His last study tour was to British Columbia in 2000.

Tom was predeceased by his son Paddy. To his wife Clare, sons Francis and Adrian and daughters Máire and Áine we offer our sincere sympathy.

'Ar dheis Dé go raibh a anam dílis.'

Michael O'Donovan

Michael McNamara
1912–2016

Michael McNamara passed away peacefully on 3rd October 2016 in his 105th year.

He was born in Cratloekeel, Cratloe, Co. Clare the fourth eldest of seven children to John and Jane (née Cherry) on 21st July 1912 – two years before the outbreak of WWI and three months after the sinking of the Titanic.

He quickly realised, on completion of his secondary education that he would have to leave home as there were few employment opportunities locally. At that time, Ireland was beginning a slow, protracted recovery in the aftermath of independence and the tragic Civil War. In his late teens, Michael mixed politics and sport both as secretary of the local Fianna Fáil Cumann and an athlete with O'Callaghan's Mills Athletic Club. He was a fine athlete and was selected for the Irish cross-country international panel. In later life Michael took up golf, a sport he excelled in for over 50 years. For much of this time, he achieved a low single figure handicap. A regular at forestry golf outings, he captained St. Anne's Golf Club, Dublin and was President of Cork Golf Club.

He received a scholarship from Clare Co. Council to attend Athenry Agriculture College in 1931 followed by two years in the Albert College, Glasnevin, Dublin. After successfully completing the Albert College course, he received two career offers. His choice lay between a three-year forestry course in Avondale or an appointment as agricultural and rural advisor with the Land Commission. The Land Commission had replaced the Congested District Board, which was dissolved in 1923.

When I interviewed him just before his 100th birthday in 2012 for a series of articles and the RTE radio programme "Sunday Miscellany", he told me that he was leaning towards the Land Commission at the time. "I had fluent Irish which this post required and I must confess that I was tempted as I would be based in the west of Ireland, probably close to my native Co. Clare," he said. "The position also offered a reasonable salary but Professor Drew – an excellent lecturer at the college – advised me to opt for Avondale. Professor Drew said that a forestry course would eventually provide a good qualification even though it offered only a paltry allowance to begin with."

He opted for forestry and when he entered Avondale in 1935, Michael, like many of his fellow students, had little knowledge of forestry and the difficult challenges that lay ahead. The training regime was tough; a mixture of manual forestry and nursery work combined with lectures by Alistair Grant, a Scottish forester. Grant was a strict but fair disciplinarian recalled Michael. “He was a good teacher but we were fortunate to also receive brilliant lectures each month from Mark Louden Anderson who was then acting director of forestry in Ireland.”

Anderson impressed him but he could be prickly and authoritarian in his relationship with students. “He was a born lecturer but the advice was ‘not to question him’ ”, advice which the youthful Clare student ignored to his peril on one occasion. “I got on very well with him until one day when he was discussing forest windthrow, I offered an alternative view to his,” recalled Michael. “My comment was given in the spirit of youthful enthusiasm, but Anderson took serious exception to my remark which he perceived as questioning his knowledge and his authority. In fact it was neither, but he barely acknowledged me after this.”

Luckily, for Michael by the time the final exams and interviews came around in 1938, Anderson had been replaced by Otto Reinhardt, a former Oberforstmeister in the Prussian Forest Service.

Michael was an enthusiastic and diligent student and he impressed Reinhardt. “Reinhardt put greater emphasis on German silviculture and was instrumental in providing two final-year students with an opportunity to further their education in Germany,” said Michael. “Joe Deasy and I were chosen and we headed for Wageningen in 1939 but had scarcely arrived when we were ordered home as the threat of World War II loomed.

He was tempted to emigrate but was offered a post as a forester in Galtee Forest, Co. Tipperary, which he accepted. He recalled humorously that after his hasty return from Germany, he was told that life would at least be more peaceful in south Tipperary. However, as it turned out, he landed in the middle of a local land war. As he cycled to a planting site one morning, he had to take shelter as gunfire echoed around him. Some of the sheep farmers who sold the hill commonages for planting wished to retain grazing rights on the newly planted land and the young Co. Clare forester stood in the way.

Despite the threats, he persevered with his work. At a hastily convened meeting in a pub in Kilbehenny to settle the dispute, his genial approach softened their attitude towards him. His arguments about the employment potential of forestry were convincing and the tide was now turning as more locals – including sheep farmers – were recruited for the Galtee Mountains planting programme. While the threat to his safety receded, the Department of Lands transferred him to Ravensdale Forest, Co. Louth as a precaution.

After Ravensdale, he was transferred to Cong Sawmill in 1940 and the following year he was back in Avondale as housemaster. Despite qualifying as a forester in 1938 and managing forests with large numbers of employees his status was a forestry foreman. “We were unestablished public service workers and when we sought Civil Service status we were refused,” he says. “We were liable to be transferred almost on a yearly basis with neither security of employment nor pension rights.”

Despite his precarious financial situation and poor prospects, he married Mona Boyle a native of Co. Donegal in 1941. He continued to fight to become an "established" public servant with reasonable conditions, but said that "nine years after qualifying my wages were still a paltry two pounds, six shillings and two pence". His final appointment as a forester in charge was in Freshford Forest, when he was based in Jenkinstown, north of Kilkenny city.

In 1948, he was promoted to the position of Assistant District Inspector. Based in Navan, he worked with the District Inspector, Roddy Crerand in an area that covered North Co. Meath, part of Co. Westmeath and Co. Cavan.

A few years later, Michael was promoted again, this time to the position of Acquisition Inspector. Now based in Dublin, his skills as a negotiator served him well in buying land from individual farmers or groups of farmers when commonages were purchased.

The Acquisition Inspector played a key role in forestry during the 1950s and 60s. "Sean McBride played a major role in setting a 10,000 ha planting target, which was eventually achieved," he said. "We more than doubled our annual intake of land especially large tracts of mountain and bogland, but when reasonably good land was included, it was usually taken over by the Land Commission," he admitted ruefully.

He recalled sad moments, especially when the vendor was emigrating or was forced to sell because there was nobody left to inherit the land. But there were also a humorous side to the job. Land was a measure of a person's status in the community and to illustrate this Michael cited an example of a land purchase deal he negotiated in Tipperary. "I had agreed a price for the purchase of 90 acres and had the various documents drawn up, but when I returned I was told that the farm had been sold to a neighbour for the same price."

A dejected Michael met the neighbour who told him that he would sell him the land within a year. "I sensed that he was speculating, so I told him I wasn't interested. But he assured me that he would sell it for the same price and sure enough, a year later, true to his word, he sold the land back at the original price." A bemused Michael asked him why go to all this bother especially as he had lost some money in the transaction due to legal fees. "I asked a girl from Limerick to marry me but her family farm was 70 acres while mine was only 40 acres," he explained. "By purchasing the 90 acres I had a farm which was much larger than the Limerick holding so my future in-laws were very impressed. Now that we are married, we are both happy to farm the 40 acres which is the best of land and every bit as good as the 70 acres below in Limerick."

He was later promoted to Divisional Acquisition Inspector and given charge of the southern half of the country. By now he was living happily in Dublin with Mona and their two sons, Fergus and Conor but sadly, this idyllic life ended in 1970 when Mona died suddenly.

As he was now in charge of acquisition in the southern half of the country and with much of the land purchasing taking place in Munster, Michael eventually moved to Cork and set up home outside the city in Little Island.

In the late 1960s he had the good fortune to meet Marie O'Connor, a secondary school teacher in Cork. They met through their involvement with the Samaritans in Cork. They were married in 1972 and a new and exciting chapter began in Michael's and Marie's lives.

Michael retired in 1976 and began a new career as a consultant forester with the support of Marie. This was a rewarding experience for both of them. By now Marie had also retired and Michael always emphasised the major role that she played in their new venture. They both enjoyed their new careers in private forestry. Michael had a wonderful retirement, he worked for 41 years in the State Forest Service and followed that with 40 years of retirement.

When I interviewed him in 2012 he looked back on his career with pride. He said that one aspect of the State forestry programme – the purchase of land – sat uneasily with him for many years. He felt that in many instances the landowner had no choice but to sell, even if many others benefited from this decision. He understood the hurt of selling land especially when forced to do so because of emigration or economic hardship.

So when the State took the visionary decision in the 1970s to create an "open forest policy", it was a very welcome development in Michael's eyes because it returned the land and the forests to all the people. Here, they could roam at will over one million acres of State forests, much of it established when the Irish economy was in dire straits. This was the tangible benefit of his work as forester and acquisition inspector.

During our interview the sale of the harvesting rights of State forests was being proposed. Michael was appalled by the decision to sell off the forests and his birthday wish was that the forests which he helped to create would continue to be forests for all our people, "forests whose value is measured not just in narrow economic terms but in their total contribution to society". He was granted his wish as the proposed sale was wisely dropped later that year.

Highly regarded and respected as a forester, Michael was elected President of the Society of Irish Foresters on two occasions, in 1963-1964 and again in 1969-1970. The last surviving founding member of the Society of Irish Foresters, he was elected an Honorary Member in 2008. Michael will always be remembered as a generous, loyal and good humoured colleague and friend; the best of company and an eloquent raconteur throughout his long and rewarding life.

We extend our sincerest sympathies to Marie, Fergus and Conor, and all Michael's friends and relatives, including his nephew Sean who followed him into forestry.

Go ndéanfaid Dia trócaire ar a anam.

Donal Magner

Dr W.H. Jack CB
1929–2017

Bill Jack passed away peacefully on the 3rd of June, 2017 at his home in Belfast where he had been cared for by his devoted wife, Daisy and his children, two of whom are doctors. The funeral service, attended by a large number of friends and former colleagues, was held in Fisherwick Presbyterian Church, a church to which Bill was much attached and where he had served as an Elder. At the service, his eldest son, Charles, gave a moving tribute to his father which was much appreciated by all who knew him.

Bill was born in the small town of Kells in Co. Antrim and was an only child. His father was the managing director of a tweed mill and his mother was from Newbliss in County Monaghan. He attended Ballymena Academy and then went to Edinburgh University to complete a degree in Forestry.

He then returned home and obtained a post with the Forest Service of the Department of Agriculture. His first post was to the small forest of Fathom in South Armagh. He said he learned a lot about personnel management but I think he did not find the job very challenging. He soon resigned and joined the British Colonial Service and was posted to the Gold Coast, now known as Ghana. This was certainly a completely new experience and there were problems with the exploitation of the natural forest resource. He developed a keen interest in the native timbers and completed his PhD thesis on the subject. On his first visit home, he drove his old Landrover all the way overland through Africa and Europe. During one of his other periods of leave, his cousin's wife introduced him to her twin sister, Daisy. She was from Ballybay in County Monaghan and was training to be a nurse in Belfast. It seems it was love at first sight and they were married for 64 years. Bill returned to Africa with his new wife, but after a few more years there the country achieved its independence in 1957.

The young couple then returned home and Bill re-joined the Forest Service. He was involved first of all with the production of Management Plans for forests. He was then appointed as Research Officer, a job he really enjoyed. He retained a long-term interest in one of his experiments – a re-spacing trial in Sitka spruce at Baronscourt Forest in Co. Tyrone. Even in his retirement he assisted the Forestry Commission's Research Branch who carried out Timber Testing on the logs from this experiment. In 1965 Bill was awarded a Kellogg Fellowship to the USA. He spent 6 months at Syracuse in New York State and a further 6 months travelling to other study centres.

Bill's talents had now been noticed within the Department of Agriculture and he was promoted to a Principal Officer post in charge of the Milk and Eggs Division which often involved negotiations in Brussels and elsewhere in Europe. Further promotions followed and he finally reached the significant position of Permanent Secretary. As was required at the time, he retired aged 60 in 1989. To celebrate his retirement, Daisy and he embarked on a world-wide tour.

Much to his surprise he was then appointed to the exalted post of Controller and Auditor to the Government of Northern Ireland. This post required the endorsement of the Prime Minister and his office was responsible for ensuring that taxpayers' money was not misspent. When he retired from this post, he was awarded the CB (Companion of the Bath) by the Queen for his outstanding public service.

At the age of 65 he still did not finally retire. He again felt the call of Africa and joined NICO (Northern Ireland Co-operation Overseas.) He travelled to Tanzania to help with their development of computer systems. He did eventually retire aged 70! He devoted the remainder of his life to his wife Daisy, to his four children, Charles, Patrick, William and Cathy, to their spouses and to his seven grandchildren whom he adored.

He was a keen member of our Society and served as Honorary Auditor for many years. He was our President from 1972-3 and was made an Honorary Member in 1995. He has been the longest serving Honorary member in the history of the Society.

Bill Jack will be remembered not only for his outstanding public service but also for his warmth, kindness, humanity and modesty. He was held in high esteem by all who knew him and worked with him. We offer our deepest sympathy to Daisy and to his children and grandchildren.

Bill Wright