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Contents

The Society of Irish Foresters

Comann Foraoiseorl na nEireann

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

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

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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 Original material only, unpublished elsewhere, will be considered for publication in *Irish Forestry*.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 sif@eircom.net (see Guidelines). Authors are requested to keep papers as concise as possible and no more than 12 pages in length (including tables and figures).
3. Submissions will be acknowledged by the Editor. Authors will be informed if the paper is to be sent for peer review. If peer review is not envisaged an explanation will be provided to authors.
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: A forest glade in Kyslinky, Slovakia which is mown regularly to provide winter fodder for deer. The hut is used by hunters. Image courtesy: LESY Slovenskej republiky, štátny podnik.

Acknowledgements
The Editors would like to acknowledge the work of Mr Austin Tobin in editing and laying out the content of this issue. Also the assistance of Kevin J. Hutchinson, and John Mc Loughlin for organising the book review section. We also thank the anonymous reviewers who have greatly contributed to maintaining the quality of the scientific and other articles published here.

Acknowledgement is also due for the mammoth work completed by a team of summer intern students who laboured relentlessly to cut up the entire back catalogue of issues into single article files, who produced metadata to describe and categorise all articles before uploading as a complete and accessible database onto a new digital platform to make this journal more accessible in digital form. The Journal Editorial Board is extremely grateful to Danielle Lopes, Julie Bibaud-Alves, Claire Corsaint, Auxane Gennetais, Fanny Meynieu and Thais Farias Pereira da Silva for their work.

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EDITORIAL

Looking back and valuing the past

All that is gold does not glitter,
Not all those who wander are lost;
The old that is strong does not wither,
Deep roots are not reached by the frost.

[From the Riddle of Strider in *The Lord of the Rings*, J.R.R. Tolkien]

Valuing the past is second nature to foresters as much of our future sits on, and grows out of, roots from the past. As the Society launches a newly updated website with a portal to a fully digitised catalogue of all articles from the published issues of this *Journal*, it is an appropriate moment to pause and appreciate the breadth and diversity of work that has been covered. Starting amid the last "war to end all wars", it is interesting to note that subjects for discussion in the 1943 volume included coniferous afforestation, thinning practices, timber production etc., but also the valuing of other non-timber attributes like "conservation of moisture, prevention of soil erosion, wind shelter, and aid to rural beauty", which all still sound extremely familiar today.

The major advantage of indexing the back issues onto the new Open Journal Software platform will be to make all material (not just peer-reviewed and technical articles) readily searchable from our own website but also from an outside interface (e.g. Google). While the new system is likely to have some teething problems, it is hoped that members and readers will inform the *Journal* about any content or performance-related issues. The laborious process of slicing up scans of past issues has impressed on me the long and continuous nature of *Irish Forestry*, and the importance of its being maintained. There are fascinating articles on all aspects of forestry in Ireland, but also from many international locations and perspectives. It is fun (now) to read some of the tit-for-tat letter exchanges! (This underlines the dearth of letters written to the Editor in recent years, which hopefully will change again.) There are even articles on how to organise forest tours (see McCusker 1980 [Volume 37(1): 31-35] in relation to the psychological needs of the forest guide). Such an eclectic trove of material that mixes at times highly technical and scientific research, with professional practice and discussion, to social records and literary digest, has long since moved beyond the ability of a person to maintain a knowledge of its content. It is high time that *Irish Forestry* was also made fully available as a digital resource!

In the current issue the value of past silvicultural practices for corrective management of broadleaved stands is explored in an article about "stumping back". As well as describing a case study from an extant trial, a review in included which covers an impressive array of truly historical literature. There is also some considerable focus within this issue on the assessment of forest growth and economic potential. Practical tools are assessed for the measurement of mature trees and the quality of those in nursery storage. Methods for assessing economic factors that affect a silvicultural system or the ecosystem services provided are described. An article exploring the opportunities for acquiring land suitable for further afforestation is particularly topical. As is its companion article which describes a classification system for judging the potential quality of an afforestation site by using mainly soil and ground vegetation criteria.

To return to the theme of valuing the past, two articles in the Forest Perspectives section describe the acquisition of the Doneraile estate and the long association of a single family with the area. These complimentary stories combine to describe a period that stretches over 500 years and details a unique and captivating history. The Book Review section carries a review about the development of a "Heritage Arboretum" at Kilmacurragh , Co. Wicklow. A review of another book, A Song for the Forest by Tom Mongan, continues this theme and describes further recollections of forestry careers.

It is a considerable pity that to date nothing is set to come of the planned Long Term Forestry Research Initiative, much heralded in 2014. Despite significant activity across the forestry research sector, it appears that a chance to make a meaningful step toward sustainably supported research, which builds on work done to date, may have been lost. While it is a laudable aspiration to support the earliest (possible) point of research careers, one would hope that the full range of career stages of those that carry out research could assume at least an equal opportunity of winning funding. It is a poor recompense for previous service to render oneself increasingly unemployable. To properly value past research investment and effort (whether monitoring plots, experimental sites, datasets, or acquired knowledge and expertise), it is imperative that systems exist to assess and maintain that which is worth keeping and to ensure that hard-won expertise is not lost simply because of longevity –that would appear ironically unfair in a forestry sector!

In preparing material for the *Journal*, I have always "enjoyed" the Obituary section. It seems to me that people "in forestry" lead particularly interesting lives and it is something of a privilege to take part in recording some even admittedly small memorial. However, I have never considered the issue of organizing my own, perhaps reflecting my current stage in life. While working on this issue of the Journal I came to learn of the arrangements some of our members have made for writing each other's obituary. I was impressed that this had occurred to them so early in life. Obviously that the choice of partner in such a venture would be crucial and the criteria for choice of the ideal candidate might easily change in the course of one's career, making new agreements (and some potentially awkward discussions) necessary. As an editor I can see the clear advantages so I would like to encourage all members and interested readers to make arrangements and to register these with the SIF office for ease of access for when it is eventually required!

To continue the theme of valuing the past and a long-term view, it is of great personal regret that I never met Niall OCarroll in person. We had several telephone conversations and quite a number of email exchanges. Quite enough for me to realise the sometimes terse nature to his character, however I finished each exchange with the feeling that the overriding motivation behind his efforts was always the furtherance of forestry in Ireland as well as an uncovering of truth (or stripping of phfaf)! In going through the back issues of our *Journal* I am continually impressed by the extent of his contributions. I am delighted that Ellen OCarroll continues the family tradition with her article "Seeing the wood for the trees" in the Forest Perspectives section. I trust and hope that Niall OCarroll's spirit will have inspired some other woodland warriors for the modern times.

Evaluation of mensuration equipment for upper-stem height and diameter measurements

Fergus McCaffery[a], Michael Hawkins[b], Mark Tarleton[c], Charles Harper[d] and Maarten Nieuwenhuis[d*]

Abstract
To assess standing timber volume and value, inventory and analysis methods are needed that can capture the precise stem form of individual trees. Most taper or tree form models perform much better if upper-stem diameter measurements are available, in addition to DBH and height values. This paper reports on the testing of hand-held tools for upper stem diameter and height measurements. The evaluation of the equipment was based on the accuracy of diameter and height measurements, the time required to carry out these measurements and the cost of the equipment. The test involved familiarisation with the equipment, followed by diameter and height measurements on four Norway spruce trees at ⅓ and ⅗ of total tree height. Both experienced and inexperienced professional foresters were included in the study.

Keywords: *Impulse Laser, TruPulse, LaserAce, Masser, Haglöf.*

Introduction

Standing volume is the most important statistic describing the economic value of forest resources. There is an increasing demand for single tree volume and taper models in Ireland due to a transition towards mixed-species stands in recent years (Forest Service 2007). Stratified sampling with permanent sample plots in the current Irish National Forest Inventory (NFI) also necessitates the use of single tree models for forest resource assessments. Pre-harvest evaluation studies conducted in Ireland highlight the requirement for an alternative to the currently used British Forestry Commission Tariff Chart system (Matthews and Mackie 2006) to better reflect regional and site specific variations in stem taper (Nieuwenhuis et al. 1999).

Therefore, volume calculation tools are required that are based on easily measurable parameters of individual standing trees, such as stem diameter and tree height. Apart from total tree volume, estimates are also required for assortments based on dimensional thresholds, e.g. the volume in the stem section between a small end diameter 7 cm and a large end diameter 14 cm. This requires the application of suitable taper models. Such models may either be segmented (e.g. Max and Burkhart 1976, Petersson 1999) or continuous (e.g. Kozak 1988, Riemer

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et al. 1995). The continuous or variable-form taper models are able to represent diameter continuously along the stem from ground to tip (Lee et al. 2003). For these volume and taper modeling approaches to produce good results, upper-stem diameter(s) should be included in the data, in addition to the diameter at breast height and tree height.

During the last 50 years, a considerable amount of data has been collected on tree stems for the main coniferous tree species in Ireland. These data have been used for the derivation of Irish stem volume models that can replace or complement British Forestry Commission tariff charts and associated functions (Matthews and Mackie 2006). Generalized stem profile models have been developed that can be used for both the calculation of stem volume and for the calculation of the volume of any part of the stem. This allows for the estimation of the potential output of assortments defined by length, and small- and large-end diameter specifications.

The objective of this study was to describe and evaluate the different inventory tools available for collecting the necessary data for use in the developed stem profile models. All relevant equipment and tools that can be used for upper stem diameter and height measurements were obtained and included in a field-testing project to determine their suitability for everyday use in inventory and management practices. This determination took into account the accuracy of the measurements, the time required to take the measurements and the price of the equipment. All these factors were then included in an overall ranking exercise. Professional foresters experienced and inexperienced in inventory work were included in the field-testing; this paper reports on the results of the project.

Material and methods

Equipment

Six pieces of equipment were tested, most of which can measure both diameters and height (Table 1). However, the Masser tool cannot be used for upper-stem height measurements and the Haglöf calipers can only be used for diameter measurements.

Test site

The equipment was tested at a site in Co. Wicklow with the following characteristics:

Name:	Knockrath Forest;
Townland:	Ballyhad Lower;
Age:	47 years (planted in 1964);
Species:	Norway spruce (*Picea abies* (L.) H.Karst.) with some Sitka spruce (*Picea sitchensis* (Bong.) Carr.);
Stocking:	526 stems ha^{-1}.

Table 1: *Key for the measurement tool codes used in the graphs and tables, listing the range of inventory tools assessed in the study. Each test involved a separate tool.*

Test number	Tool	Product information
1	Impulse Laser Rangefinder with fixed scope	http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=1376
2	Impulse Laser Rangefinder and Criterion RD1000 Dendrometer with adjustable scope	http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=3873
3	TruPulse 360 R Laser Rangefinder with adapted graduated scope	http://www.lasertech.com/TruPulse-Laser-Rangefinder.aspx
4	LaserAce 1000 Laser Rangefinder	http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=384
5	Masser RC3h	http://www.masser.fi/product-category/rc3h-bt/ Cannot measure height of upper measurement point
6	Haglöf Gator Eyes	http://www.forestry-suppliers.com/product_pages/View_Catalog_Page.asp?mi=8761 Cannot measure heights

Field test layout

The test consisted of carrying out measurements on five Norway spruce trees, one of which was the control tree and the other four were test trees. The control tree was used to give the tester a chance to get familiar with the equipment. The testers were given the correct values of each measurement after completing it, and they could repeat the measurements if they felt this would be beneficial. The control tree characteristics were:

- all branches removed within the measurement area;
- clear view of the stem at the points of measurement.

After familiarizing themselves with the equipment using the control tree, the testers carried out measurements on each of the four test trees with each piece of equipment. With the Masser (test 5) and Haglöf (test 6) only two measurements could be made. The test trees' characteristics were:

- natural state;
- not brashed;
- measurement points possibly obscured;
- testing of equipment under normal conditions;
- two points marked for test at ⅓ and ⅗ of total tree height.

Data overview

Six people took part in the testing of the equipment, three of them experienced forest inventory staff and three inexperienced colleagues. Each tester made four measurements with a piece of equipment, where possible: two height measurements and two diameter measurements. Due to time constraints, not all testers completed measurements with all pieces of equipment. The measurements by all testers were made from the same direction to the trees and the testers could select the distance to the trees from which the measurements were taken freely. The true values were obtained by climbing the trees and measuring the heights of the measuring points with a tape and the diameters with a callipers perpendicular to the direction from which the testers took their measurements.

The results of the evaluation process presented in this paper are based on the data for these six testers. In the first section, we deal with diameter, and in the second section, we focus on height. In the third section, diameter and height were analysed together, while in section 4 volume was examined. Following these sections, dealing with measurement accuracy, the time required to carry out the measurements and the cost of the equipment were analysed to arrive at a cost per measurement value. Finally, in the Discussion and Conclusion section, the accuracy results are combined with the cost findings to produce a ranking of the equipment, for both experienced users and for the inexperienced users.

Results

Diameter

Relative errors for the lower and upper diameter points are presented in Figure 1, for experienced and inexperienced testers separately. The same trends towards higher accuracies for the lower measurements are revealed, and the accuracies for the experienced testers seem lower than those for the inexperienced ones. When lower and upper errors are analysed together for each tree and each test (only tests 1 to 4 are included as these pieces

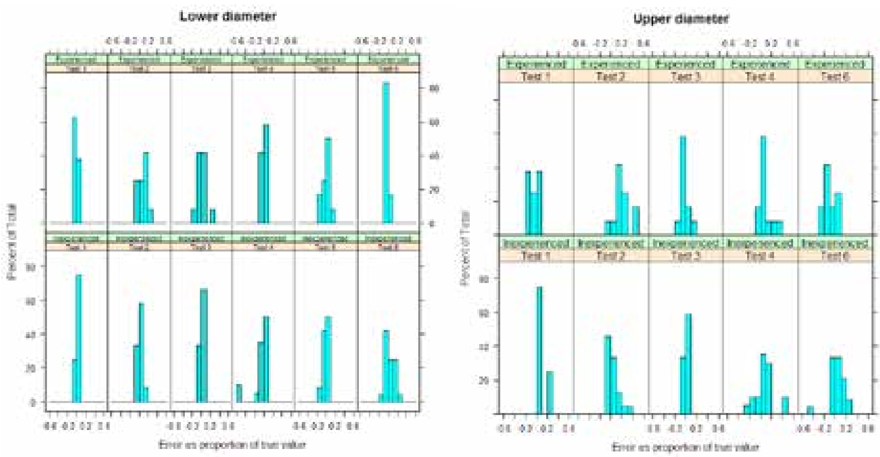

Figure 1: *Tests 1 to 6 (see Table 1 for list of equipment used in each test) compared diameter estimates made by experienced and inexperienced operators with true measurements. Relative lower (left) and upper (right) diameter errors classified by experience level and test method. (Test 5 did not include upper diameter measurements.)*

of equipment can measure both diameters) clear differences start to appear, with tests 1 and 3 producing much better results than test 2 and, especially, test 4 (Figure 2).*Height*

The results for the height measurements are in general, very good, both for the lower and upper points, but when the accuracies for the individual pieces of equipment are analysed for both the lower and upper points, a clear trend appears where for all tests the accuracies are reduced at the upper point, especially for tests 2 and 4. Analysis by test and experience level indicated difficulties with test 4 for both experienced (at the upper point) and inexperienced (at upper and lower points) testers (Figure 3).

An analysis of the relative errors by tester, test and tree, for the lower and upper measurements combined, clearly indicated that test 4 had the largest errors for a number of testers (Figure 4) and errors occurred both at the lower and upper points. A detailed analysis of test 4 revealed that especially some of the inexperience testers had problems with this piece of equipment. test 2, which appears to produce good results, when analysed separately, produced very small errors except for one observation by an experienced tester.

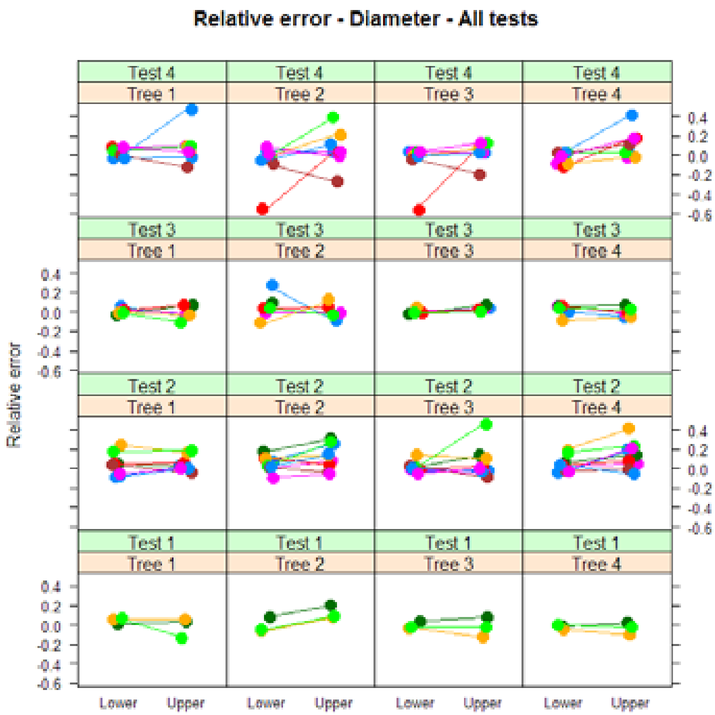

Figure 2: *Relative diameter error ((true – test) / true) classified by tester (colours), test, tree and measurement point (lower and upper). (Test 5 did not perform upper stem measurements; test 6 did not perform height measurements.)*

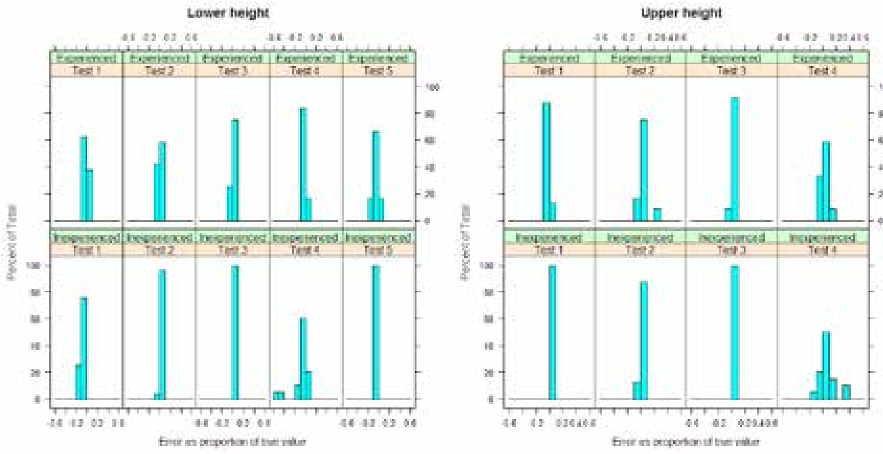

Figure 3: *Relative lower (left) and upper (right) height errors classified by level of experience and test method. (Note: test 5 did not perform upper stem measurements; test 6 does not perform height measurements.)*

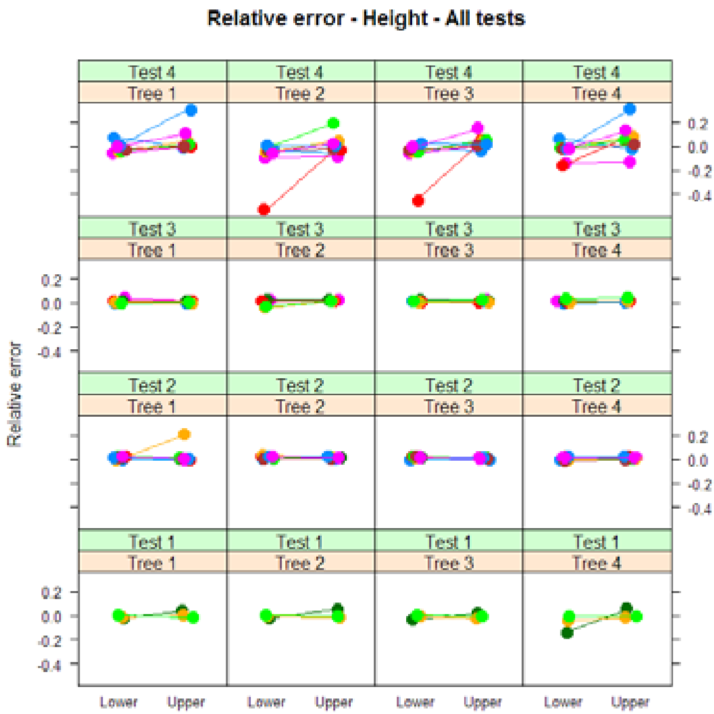

Figure 4: *Relative height errors grouped by testers (colours), tests, trees and measurement point (lower and upper).*

Diameter and height combined

To investigate how the pieces of equipment performed at both height and diameter measurements, combined graphs of relative errors have been produced. When experienced and inexperienced testers are analysed separately, tests 3 and 1 produced the best results (it should be noted that the results for test 5 only relate to the lower stem measurements) (Figure 5).

When analysing the relative errors separately for each test, for each tree for each tester, and looking at the combination of diameter and height, it is obvious that some pieces of equipment performed much better than others (Figure 6). Tests 1 and 3 show much better results than tests 2 and 4, with test 4 producing the worst results. In the test 3 data, it is interesting that the tree 2 measurements, both at the lower and upper points, produced larger errors than those for the other trees.

Volume

To get an indication of how the measurements of diameter and height combine into volume estimation, the volume of the frustum defined by upper and lower diameter and the height difference between them was calculated. The frustum volume formula is:

$$\text{Frustum volume } (m^3) = \pi\, h\, (D^2 + d^2 + D\, d)/12 \qquad (1)$$

where D is the lower diameter (m), d the upper diameter (m) and h is the difference (m) between the upper and lower heights.

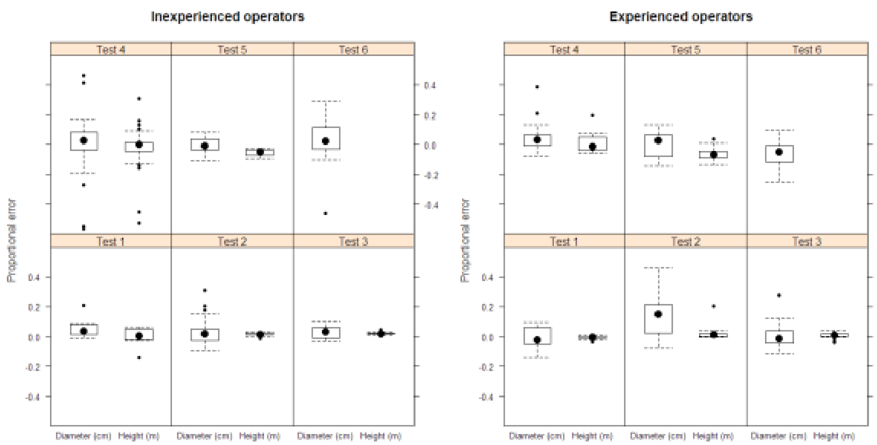

Figure 5: *Relative error classified by measurement type and test method for* inexperienced *(left) and* experienced *(right) operators. (Note: test 5 did not perform upper stem measurements; test 6 did not perform height measurements.)*

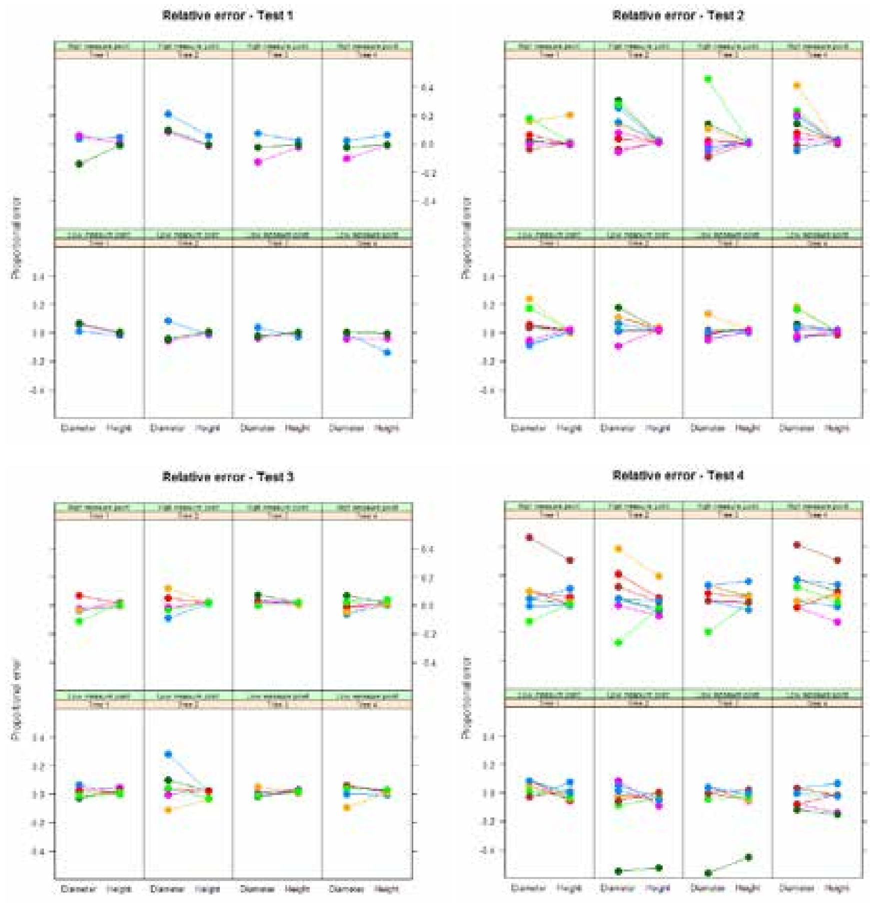

Figure 6: *The relationship between height and diameter errors classified by tree, tester (colour) and measurement point (low and high), for Test 1 (top left), Test 2 (top right), Test 3 (bottom left) and Test 4 (bottom right). Lines join height-diameter pairs of measurements i.e. measurements at the same point on the same tree by the same tester.*

Comparions were made using combinations of the actual and estimated values (Figure 7). A general skewness is identified (the vast majority of ratio values > 1.0), indicating that the true volumes were on average larger than those estimated using one or both estimated components. The results demonstrated the overall better result using test 3. Test 2 performed very well for the true diameter – estimated height combination, apart from one outlier (Figure 7b), but very badly for the test diameter – true height combination (Figure 7a). In Figure 8, the same analysis is shown separately for inexperienced and experienced testers. The strong performance of test 3 for both sets of testers for the test diameter – test height combination is very apparent.

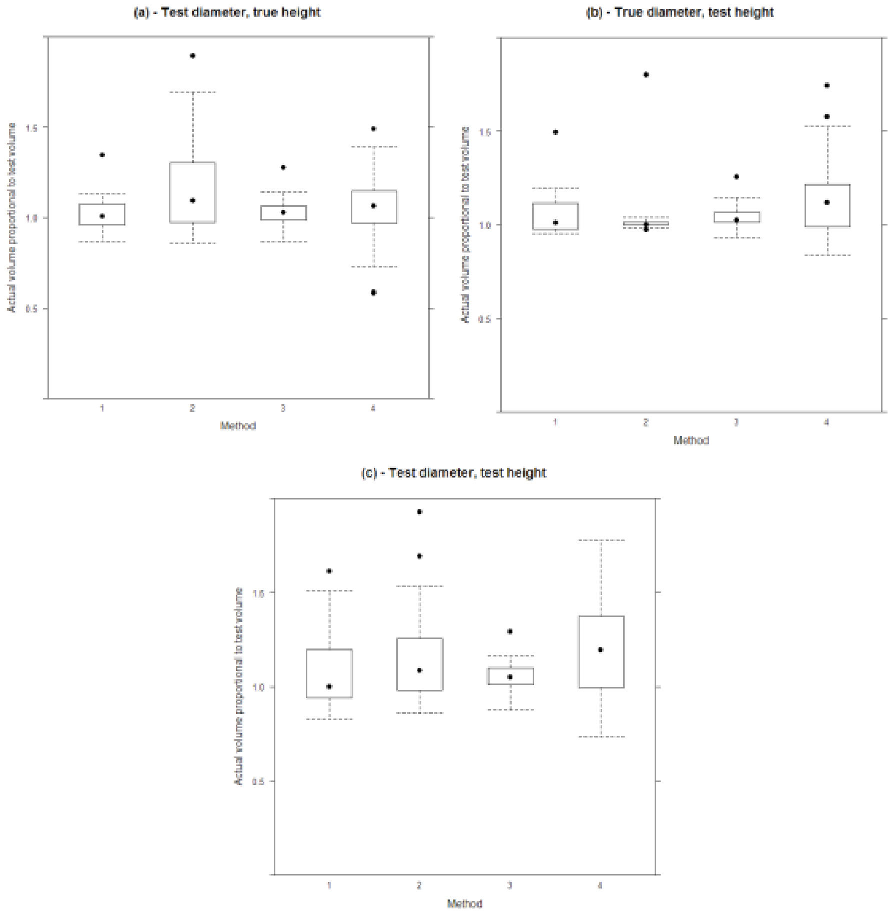

Figure 7: *Box-whisker plots of relative frustum volumes classified by method (test 1 – 4). The variable presented is the ratio of the frustum volume calculated using the* true height *and* diameter *measurements and the frustum volume calculated using either* estimated diameter *and* true height *(panel a), estimated height and true diameter (panel b) or both* estimated height *and* estimated diameter *(panel c).*

Time consumption

Apart from the accuracy of the measurements, another criterion that should be used to evaluate the suitability of the test equipment for operational use is the time consumed in carrying out the measurements. Figure 9 illustrates that test 3 resulted in the best outcome for both inexperienced and experienced testers, while tests 1 and 2 worked well for experienced testers but not for inexperienced ones.

Cost effectiveness

Factors involved in cost effectiveness are the hourly cost of the equipment over the

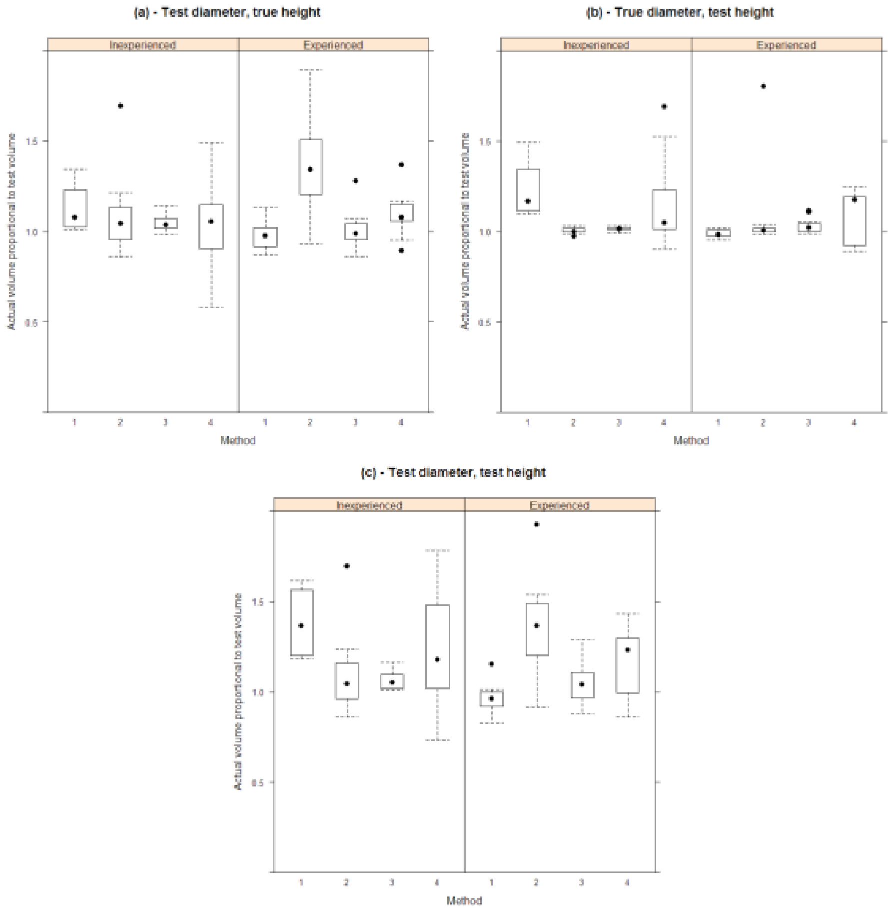

Figure 8: *Box-whisker plots of relative frustum volumes classified by method (tests 1 – 4) and experience level of operator (experienced, inexperienced). The variable presented is the ratio of the frustum volume calculated using the* true height *and* diameter *and the frustum volume calculated using either* estimated diameter *and* true height *(panel a),* estimated height *and* true diameter *(panel b), or both* estimated height *and* estimated diameter *(panel c).*

standard depreciation schedule, and the time required to carry out the measurements with the different pieces of equipment. These factors are summarised in Table 2. The final column combines the cost of the equipment with the mean measurement time observed per set of measurements, equipment type, and experience level. Test 3 resulted in the best outcome for both experienced and inexperienced users.

Discussion and Conclusions

The setup of the test introduced some artificial constraints that could have influenced the results. All measurements had to be taken from the same direction to ensure that

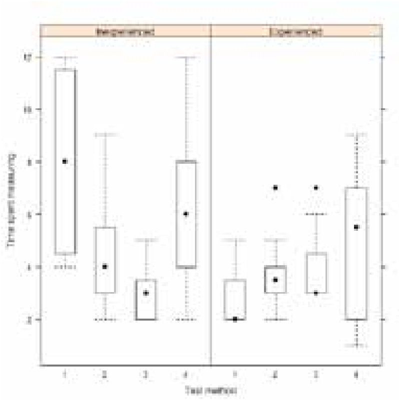

Figure 9: *Measurement time for each method (tests 1 – 4) classed by operator's level of experience.*

the same true diameters were assessed, and testers were forced to take the diameter measurements at the heights indicated on the stems. For the four pieces of equipment that were capable of measuring heights and diameters, these test requirements did not affect the outcome, except maybe in the case where the view of the stem at the measuring point was (partly) obscured from the direction of measurement and the tester, in practice, could have selected another measuring direction or a different measuring height to get a better view. However, the testers were free to change the distance from the trees from which the measurements were taken, so occlusion of the stems was not a real problem.

In general, the pieces of equipment performed either well overall or not at all. Equally, most of the pieces of equipment performed similarly for experienced and inexperienced users, with the exception of test 1, which came first for experienced

Table 2: *Costs (equipment purchase, correct for 2008) and costs per hour (assuming depreciation period of three years and a schedule of fifty, five-day weeks and eight-hour days (~ 6,000 hours), time taken per set of measurements (i.e. two heights and two diameters) and cost per set of measurements, for experienced and inexperienced users.*

Test	Cost (2008) (€)	Cost per hour (€ hr^{-1})	Time per set (experienced / inexperienced) (hr set^{-1})	Cost per set (experienced / inexperienced) (€ set^{-1})
1	3,817	0.63	0.048 / 0.127	0.03 / 0.08
2	4,170	0.69	0.058 / 0.072	0.04 / 0.05
3	1,500	0.25	0.080 / 0.040	0.02 / 0.01
4	1,620	0.27	0.074 / 0.011	0.02 / 0.03
5	945	0.16	NA	NA
6	595	0.10	NA	NA

Table 3: *Overall assessment rankings, for both experienced and inexperienced users, based on the cost of the equipment, the time taken to carry out the measurements, and the accuracies obtained for height and diameter measurements and volume estimation.*

	Experienced users						
Equipment	**Test**	**height**	**diameter**	**volume**	**cost**	**time**	**Sum of rankings**
Impulse	1	2	1	1	3	1	8
Criterion	2	3	4	4	4	2	17
TruPulse	3	1	2	2	1	3	9
LaserAce	4	4	3	3	2	4	16

	Inexperienced users						
Equipment	**Test**	**height**	**diameter**	**volume**	**cost**	**time**	**Sum of rankings**
Impulse	1	2	2	3	3	4	14
Criterion	2	3	3	2	4	2	14
TruPulse	3	1	1	1	1	1	5
LaserAce	4	4	4	4	2	3	17

users but a distant shared second for inexperienced users.

Based on the accuracy levels obtained for height, diameter measurements and volume estimation, combined with the cost of the equipment and the time required to do the measurements, a ranking of the equipment has been drawn up for each factor and for all factors combined (assuming equal weights) (Table 3). Test 1 comes out on top for experienced users, very closely flowed by test 3. Test 3 performed best with inexperienced users, while test 1 provided low quality results for inexperienced ones. Test 3 would be the recommended equipment if it was to be used by both experienced and inexperienced users. Of course, the weightings that different users might put on accuracy, efficiency and price could influence the outcome of the overall evaluation.

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Rapid assessments of cold hardiness and quality deterioration during storage of bare root conifer transplants

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Abstract
Chlorophyll fluorescence and trace gas analysis techniques were evaluated with the aim of providing nursery and establishment managers a rapid prediction of dormancy status and seedling quality deterioration during storage. Dark-adapted maximal fluorescence (Fv/Fm) assessments of excised shoots following freezing treatments accurately predicted cold tolerance as determined using the temperature at which 50% of seedlings are damaged (LT_{50}). The Fv/Fm of excised shoots was correlated with visual assessments of needle damage and survival following extended storage of seedlings at different temperatures. We suggest that these Fv/Fm-based methods provide a more rapid and robust indicator of seedling quality during period of extended storage when compared to other physiological measures, such as root electrolyte leakage (REL) and the build-up of volatile compounds such as ethanol and ammonia. This modified fluorescence-based estimate of LT_{50} ($F.LT_{50}$) can be conducted within 3 days, compared to 14 days using the conventional visual assessment LT_{50}. The $F.LT_{50}$ fluorescence based technique is now been routinely used to assess hot lift and cold storage suitability of Sitka spruce seedlings in Coillte nurseries.

Keywords: S*eedling quality, hardiness acclimation, deterioration in storage*.

Introduction
The use of freshly lifted and cold stored bare-root seedlings to establish a forest is a common silvicultural practice in both Ireland and the U.K. Nursery production factors or management decisions which influence the likelihood of successful seedling establishment include dormancy status of the material before lifting and the amount of seedling quality deterioration during cold storage or on site before planting (McKay 1992 and 1993, Mason 1994, O'Reilly et al. 1999).

Lifting and cold storage of insufficiently hardened trees may lead to reduced vitality, frost damage and desiccation. Although lifting and planting windows have been well established for most commercially grown species, these guidelines should be interpreted carefully (O'Reilly and Keane 2002) because the recommendations reflect average conditions that prevail over relatively large geographical locations and dormancy status or stress resistance levels vary considerably from year to year

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or from nursery to nursery (Ritchie 1984). The routine identification of lifting and cold storage windows requires rapid characterisation of hardening acclimation using plant physiological or phenological indicators. The most common testing procedure for conifers involves the visual assessment of shoot damage after artificial freezing to estimate temperature at which only half the seedlings (LT_{50}) would recover. The method has been shown to be consistently related to hardening and de-hardening acclimation processes and field performance after different lift dates in many species (Colombo et al. 1989, O'Reilly et al. 1999, 2000). However, this method is of limited practical value because of the long period required for visual damage symptoms to develop (up to 14 days depending on extent of freeze damage).

Following dispatch, seedlings are often left on site for extended periods before planting. This has been suggested to be one of the reasons for establishment failure in Ireland (O'Reilly and Keane 2002). This warrants the development of an operational test to assess seedling quality on site if quality deterioration is suspected. Whilst numerous tests have been developed to assess seedling quality during storage, few are rapid and simple enough to routinely use under operational conditions. Physiological assessments of seedling survival potential following periods of extended storage have been determined by assessing root membrane integrity through measurement of root electrolyte leakage (e.g. McKay 1992). This method is best suited for use under laboratory conditions and results are difficult to interpret in some cases (O'Reilly et al. 2000).

The use of two techniques for rapid analysis of seedling quality under operational conditions is investigated in this study:

a) Chlorophyll fluorescence, a proxy field measurement of photosynthesis., is a rapid, non-destructive method for assessing seedling survival potential of numerous forest seedling species in response to stress (Perks et al. 2000, Black et al. 2005, 2008). Perks et al. (2004) demonstrated a rapid method for freeze tolerance using chlorophyll fluorescence of shoots ($F.LT_{50}$) following artificial freezing. This can potentially reduce the time to derive results to 3 days, when compared with up to 14 days for the more traditional visual assessment LT_{50} technique. We report on the further development of a quick, cheap, simplified $F.LT_{50}$ method, initially developed by Perks et al. 2004) for routinely assessing dormancy status of conifer crops under operational conditions over six seasons.

b) The use of a method to rapidly analyse volatile compounds in the airspace of storage bags to detect fermentation activity or ammonia build up, which is indicative of plant decomposition during storage, is reported. These techniques, together with simple chlorophyll fluorescence assessments, were developed with the aim of providing a cheap rapid test of seedling quality under nursery or field conditions.

Materials and methods

Description of nurseries

Bare root transplants were grown at Ballintemple nursery, Co. Carlow (52° 44’ N, 06° 42’ W, 100 m elevation) and Killygordon nursery Co. Donegal, Ireland (55° 15’ N, 07° 35’ W, 80 m elevation). The Ballintemple nursery soil is a brown earth with a pH of 5.7, 8–12% organic matter content and sand, silt and clay fractions of 66, 19 and 15%, respectively. The soils in Killygordon are also represented by a brown earth with a similar pH, 7-9% organic matter and a sand, silt and clay content of 69, 21, and 10%, respectively. Plants received monthly additions of nitrogen at c. 150 kg N ha^{-1} from April to July, with top dressings in July of P, K and Mg in the final year to achieve a final top height of 60 cm (c. 50 kg P, 100 kg K and 30 kg Mg ha^{-1}).

On each sampling date, seedlings of Sitka spruce (*Picea sitchensis* (Bong.) Carr.), Norway spruce (*Picea abies* (L.) H.Karst), lodgepole pine (*Pinus contorta* Dougl. ssp. *contorta*), Scots pine (*Pinus sylvestris* L.) and Douglas fir (Pseudotsuga menziesii (Mirb.) Franco) were lifted and graded as per normal forest nursery operational practice. Graded seedlings were placed in polyurethane coextruded bags (see different experiment’s sample numbers below) and labelled prior to dispatch to University College Dublin (UCD).

Nursery climatic conditions

The air temperature at 2 m above the crops located at both nurseries was monitored using temperature loggers (Tingtag, Gemini data loggers, U.K.) to derive a measure of accumulated day degrees above 5 °C for May to December from 2006 to 2011 (O’Reilly et al. 2000). Data for Killygordon was only collected for the period 2006 to 2008. The number of cumulative chilling hours below 0 °C from May to December was also calculated as an indicator of ground frost frequency (Keane and Sheridan 2004).

Experiment 1: Evaluation and calibration of physiological indicators of seedling dormancy

Transplants from Ballintemple and Killygordon nurseries were lifted at 1 to 4 week intervals from September to April for the 2006/7 and 2007/8 seasons and dispatched to UCD for freeze tolerance and root electrolyte leakage (REL) assessments. On each sampling occasion, all physiological assessments were performed using eight seedlings per bag, replicated three times (three bags per sampling interval).

Standard cold hardiness tests (LT_{50})

To assess the accuracy and predictability of the newly developed fluorescence-based cold hardiness test ($F.LT_{50}$), a standard cold hardiness (LT_{50}) method, as described by (O’Reilly et al. 2000), was used as a comparison. This was conducted only on the Sitka spruce Washington provenance plants. The sampling frequency of the standard LT_{50} test was reduced to once a month. First-order lateral shoots (10-15 cm long), representing the current year's growth, were excised from seedlings (n = 10) and placed in empty spectrophotometer curvette styrofoam holder trays (10 × 10 rows, CEL1060, Spark laboratory suppliers, Dublin) prior to freezing. Sets of trays were then subjected to a series of target freeze temperatures -4, -8, -12, -20 and -30 °C (10 shoots × 5 temperatures × 2 nurseries × 3 reps per sample point). The programmable freezer was set to cool from ambient room temperature (c. 20 °C) to the desired temperature at a rate of 6 °C h^{-1}. The freezer temperature was maintained at the target temperature for 3 h and then warmed at a rate of 10 °C h^{-1} to 10 °C. The series of freeze temperatures were selected to bracket the range causing 50% damage, as subsequently assessed by visual examination of needles. On removal from the freezer, the cut base of excised shoots were submerged in tap water by filling the styrofoam trays and placed in a controlled environment chamber (Vindon Scientific Ltd., UK) at 20 °C day/night, 16 h photoperiod, and an irradiance of 300 μmol m^{-2} s^{-1}. Visual assessments of needle damage were made after 14 days incubation in a controlled environment (Cannell et al. 1990). Scores were based on the degree of browning of the current year's needles, in increments of 10%. The temperature damaging 50% of the needles (LT_{50}) was estimated using the GLM procedure of SAS v 9.1. (after O'Reilly et al. 2000). The results of previous research has shown the validity of this approach for determining lifting windows for Sitka spruce and other conifer species (O'Reilly et al. 1999, 2000).

<u>Fluorescence-based cold hardiness (F.LT_{50}) assay</u>

Modifications to the original quick freeze tolerance method described by Perks et al. (2004) included:

a) The use of domestic chest freezers instead of programmable freezers, thereby reducing setup costs, but re-producing a freeze profile similar to that obtained using programmable freezers.

b) A reduction in the number of target freeze temperatures required to determine LT_{50}. Domestic chest freezers were set up to maintain a constant temperature of -4, -12 and -30 °C. The series of target temperatures were reduced to simplify the method, reduce labour costs and turn-around time, which is an important pre-requisite for the establishment of a routine operational assay. These specific temperatures where selected to bracket the range causing 50% damage over the hardening phase for the establishment of hot lifting and lifting for cold store windows using the thresholds described by O'Reilly et al. (2000, 2002).

c) Control of cooling and heating rates in domestic freezers.

A series of tests were conducted to manually control the cooling and heating rates similar to those obtained with the programmable freezer. This was achieved by placing the shoots (in Styrofoam holder trays, as described above) in 50 mm thick Styrofoam boxes with internal dimensions of 19 (l), 21 (b) and 26 cm (h) (provided by Sigma Chemicals, U.K.) prior to the freezing treatment. The temperature inside the Styrofoam boxes was monitored using temperature loggers. A separate box of shoots was used for each target temperature. The cooling and heating rates within the freezing/melting point range were reduced by adding 50 ml of tap water to each Styrofoam box before freezing. A cooling rate of <6 °C h^{-1} was achieved, which reduced the formation of large ice crystals in tissues (Figure 1). All boxes were placed in the freezer destined for freezing to -4 °C overnight; this freezer had been switched off and allowed to warm-up to ambient temperature. A timer switched the freezer on at 4.30 am, which cooled the samples to c. -4 °C by 9 am. At this time, one box was left at -4 °C for 4 h while the other two were transferred to the -12 or -30 °C freezer for 5 and 7 h, respectively (Figure 1). Once the target temperature was maintained for c. 3 h, the -12 or -30 °C treatment boxes were transferred back to the -4 °C freezer for 1 h, removed from the freezer and allowed to warm up at ambient conditions in the lab. (c. 20 °C). Trays containing the shoots were removed from the boxes, filled with tap water and incubated in the controlled environment chamber at 20 °C for a minimum of 4 h in the light before fluorescence assessments were performed.

Estimation of $F.LT_{50}$

Dark-adapted maximal fluorescence (Fv/Fm) was determined within 24 h of the freeze

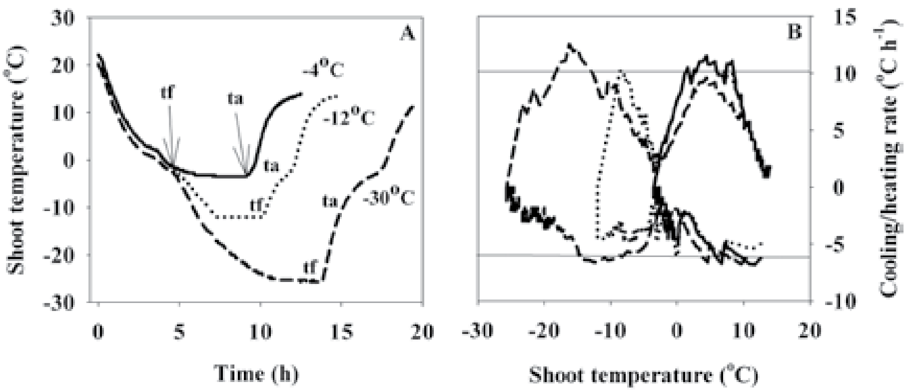

Figure 1: *The final freeze profiles (A) and cooling/warming rates as a function of shoot temperature (B) for different target temperatures (-4 (solid line), -12 (dotted line) and -30 °C (short dashed line), using the modified cold hardiness methodology. The symbol* ***tf*** *indicates when the boxes for the -12 and -30 °C target temperatures were transferred from the -4 °C freezer to respective freezers and returned after 5 to 7 hrs. The symbol* ***ta*** *indicates were boxes were removed from the -4 °C freezer and left at room temperature. The solid grid lines in Figure 1 B indicate the desired maximum cooling and heating rates during the freezing protocol.*

treatment using a modulated fluorimeter (Hansatech PEA2, Hansatech Instruments Ltd, Kings Lynn, UK) as described by Perks et al. (2004). An empirical equation was used to predict cold tolerance using dark-adapted (Fv/Fm) fluorescence measurements (Perks et al., 2004). In order to allow for the operationalisation of the Fv/Fm method, Perks et al. modified the original equation published by Fisker et al (1995). This was done by assuming that the Fv/Fm at which LT_{50} occurs (i.e. $F.LT_{50}$) at a threshold fluorescence value of approximately 0.43-0.59, depending on species (Eq. (1), Table 2), as evidenced from experimental data (see Figure 2). The $F.LT_{50}$ was determined using the following formula (Perks et al. 2004):

$$F.LT_{50} = \frac{F50 - F2}{\beta} + T2 \qquad (1)$$

The Fv/Fm value at which 50% (F50) of the shoots died was determined using regression analysis (Figure 2). F2 is the mean Fv/Fm value for shoots (n = 10) subjected to the lowest freeze temperatures (usually -12 or -30 °C depending on extent of cold hardiness), T2 is the freeze temperature (-12 or -30 °C).

$$\beta = \frac{F1 - F2}{T1 - T2} \qquad (2)$$

where F1 is the mean Fv/Fm value for shoots (n = 10) subjected to a sub-lethal temperature and T1 is the sub-lethal temperature (-4 or -12 °C).

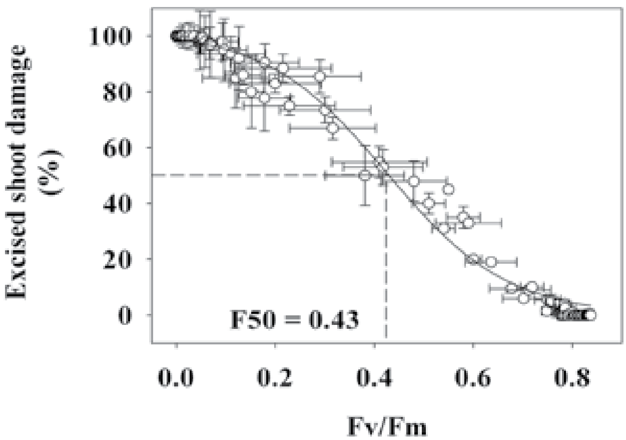

Figure 2: *Relationships between mean fluorescence (Fv/Fm) and visual assessments of needle browning from grouped means (n = 30) over all sample dates lift dates and freeze temperatures from both the Ballintemple and Killygordon nurseries over the 2006/7 season (using paired mean data).*

Table 1: *Species and provenances sampled for F.LT50 assays over the period 2006 to 2011. The threshold fluorescence at which 50% of samples do not survive (F50) value used in Eq. 1 was obtained from the overall regression of grouped data for each provenance of species in the form of a 3 parameter sigmoidal function.*

Species	Provenance	Seed source	F50
Sitka spruce	Washington	SW-IERATH-A140	0.43
Sitka spruce	QCI	SQ-DKFP622-E12	0.45
Sitka spruce	Oregon	SR-ORO53-W72	0.47
Lodgepole pine	Northern	LN-UKNT15-J60	0.49
Lodgepole pine	Southern	LS-IEGY-J27	0.52
Norway spruce	Lund	NS-DKLUN-J65	0.59
Scots pine	Scottish	SP-IEWX-F57	0.53
Douglas fir	Washington	DF-WA030-H79	0.50

Root electrolyte leakage (REL)

Measurements of REL were determined on excised fine roots (<2 mm diam., fresh mass 300–500 mg) of three plant replicate bags (10 seedlings per bag) for each lift date. The relative conductivity method of Wilner (1955) was used to determine REL, following the modifications of McKay (1992).

Experiment 2: Seasonal patterns for dormancy acclimation and dehardening for six conifer species

Following calibration of the quick $F.LT_{50}$ methodology, additional assessments were performed using six different conifer crops from 2006 to 2011 (See Table 1). For these assessments, all of the crops were grown at Ballintemple nursery under the same conditions as those described under the seedling material section. Sampling was limited to this nursery for the time series due to logistical reasons and because of the limited numbers of species produced at the Killygordon nursery. The assessments were made on three provenances of Sitka Spruce, QCI, Washington and Oregon material. Two provenances of lodgepole pine were also tested over the same period. Characterisation of the threshold fluorescence vales was determined for each species (Table 1). On each sampling occasion, six to eight seedlings were used from each of three replications (bags).

Experiment 3: Indicators of quality deterioration in the field

The potential impact of plant quality status on seedling performance was assessed using Sitka spruce (2+1) of Washington provenance (seed lot SW-IERATH-A140) samples at Ballintemple nursery. Cold stored seedlings (72 bags of 50 seedlings each), lifted at Ballintemple nursery, were graded, packed in polyurethane coextruded bags and cold stored (at 1 to 2 °C) in January 2005, were dispatched to UCD in March 2006 for the storage deterioration experiment. Tap water (2 l) was poured over seedlings in half of the bags to simulate the lifting and packaging of wet seedlings. Each bag was sealed in a second polyurethane coextruded bag before dispatch to UCD to minimise the likelihood of puncturing and loss of air from the inside of the bag during transport and handling.

Bags set up in a factorial design with soaked (wet) and non-soaked (dry) bags, incubated at 5, 10 and 20 °C in controlled environment chambers (Vindon Scientific Ltd., UK) for a total of six treatment combinations (2 bag moisture × 3 temperatures). The inside temperature of the bags was recorded using temperature loggers (Tingtag, Gemini data loggers, U.K.). Three bags were sampled at 0, 1, 5, 10, 14, 21, 25 and 32 days after initial storage for REL, Fv/Fm, visual needle damage assessments, seedling survival and quantification of volatile compounds.

Seedling survival

Sampled seedlings from the experiment were planted into 2 l pots containing a 3:1 (v/v) mixture of peat compost and perlite and placed in a controlled environment chamber (Vindon Scientific Ltd., UK) at 20/16 °C day/night, 16 h photoperiod, and PPFD of 300 mmol m^{-2} s^{-1}. Pots were regularly saturated with tap water and survival was recorded after 3 weeks. Plant condition was assessed using a plant health index based on needle browning, for the whole plant (value range: 100% = brown, presumed dead to 0% = completely green, presumed healthy).

Volatile compounds

A replicate set of treated bags from the experiment (described above) were sampled at the same time intervals for volatile ethanol and ammonia assessments using the Gastec detector tube system (Gastec Corporation, Ayase City, Japan). Ethanol is a product of fermentation resulting from the breakdown of sugars and has been suggested to be indicative of deterioration of seedling tissues during storage (Steve Colombo, pers. comm. 2005). The ethanol concentration of air in the bag head space was measured using Gastec 112L tubes with a detection limit of 5 ppm over a range of 50 to 200 ppm in air and an accuracy tolerance of 25% using the Gastec multi-stroke gas sampling pump (Model GV 100S, Gastec) as described by the manufacturer. Ammonia, a breakdown product of plant proteins during decomposition, was also measured using Gastec 3L tubes with a detection limit of 0.2 ppm over a range of 0.5 to 78 ppm. Air in sealed bags was sampled by puncturing the coextruded bag with the tip of the sample tube and extracting 100 to 200 cm^3 air using the GASTEC pump, depending on type and concentration of the volatile compound (see 112L and 3L product information charts www.Gastec.co.jp). Holes in the bags created by the insertion of tubes were sealed with insulation tape after each sample was taken.

Statistical analyses and data presentation

Percentage and index scores for REL, needle damage and plant survival values were transformed to arc sine, square root values prior to analyses. Concentration values for volatile compounds were log transformed to normalise the data before ANOVA analysis.

The effects of soaking, incubation time, incubation temperature and their interactions with mortality, REL, volatile organic compounds and Fv/Fm during storage was analysed using Fisher's PSLD method of analysis of variance (ANOVA) in SAS v.9.1 (SAS Institute Inc., Cary, NC). Significance levels quoted are at $p < 0.05$. The relationship between the physiological measures and seedling survival was evaluated using the regression procedure in GLM of SAS v.9.1 (SAS Institute Inc., Cary, NC).

Non-linear regression analysis of Fv/Fm and seedling condition was performed on un-transformed data using a three parameter sigmoidal function using SigmaPlot (v 8.0, SSPS Inc. USA).

Analysis of REL and F.LT_{50} values of seedlings lifted from Ballintemple and Killygordon nurseries for the 2006/7 season was compared using Fisher's PSLD method of ANOVA in SAS. Comparison and regression analysis of conventional LT_{50} and F.LT_{50} mean values were conducted using polynomial regression and residual analysis (SigmaPlot v. 8.0, SSPS Inc. USA).

Results

Experiment 1

A. Validation and calibration of the rapid F.LT_{50} technique

An important calibration of the rapid F.LT_{50} method was the determination of the Fv/Fm value at which 50% (F50) of the shoots died for the parameterisation of equation 2 (see Materials and methods). A F50 value of 0.43 for the Washington provenance of Sitka spruce was obtained by regression analysis of needle damage scores following freezing and chlorophyll fluorescence assessments of shoots taken from seedlings lifted at Ballintemple and Killygordon over the 2006/7 season (Figure 2). The relationship between shoot damage and Fv/Fm across different freeze temperatures did not vary when values for shoots from Killygordon or Ballintemple were compared.

Estimates of cold hardiness using the rapid (3 days) Fv/Fm-based assessment of needle damage following freezing in domestic freezers (F.LT_{50}) compared well with conventional visual needle damage assessments (LT_{50}), performed 14 days after freezing in the programmable freezer (Figure 3). The partial coefficients (i.e. the slope and y-intersects) of the linear relationship between LT_{50} and F.LT_{50} estimates did not vary when values for seedlings taken from Killygordon and Ballintemple were

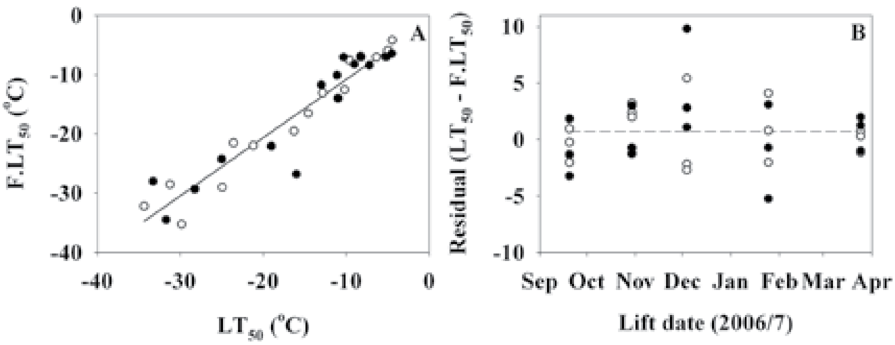

Figure 3: *A linear regression showing the comparison of conventional visual assessments (LT50) and instantaneous Fm/Fm estimates (F.LT50) of cold hardiness (A) and comparison of residuals as a function of lift date (B) for seedlings lifted from Ballintemple (○) and Killygordon (●) nurseries during the 2006/7 season. The solid regression line (A) indicates a significant relationship (r2 = 0.91, p < 0.001, slope = 1.03, SEE = 3.1). The broken regression line (B) for the residuals over time was not significant (r2 = 0.002, p = 0.87).*

analysed separately and compared. The F-values (156 and 169) and standard error of estimate (3.5 and 3.3%) for data derived from the two nurseries were also similar. Therefore, data from both nurseries were pooled for combined regression analysis (Figure 3). Regressions and residual analysis suggested that $F.LT_{50}$ was neither under- nor over-estimated, when compared to conventional LT_{50} assessments, in different nurseries and across different lift dates.

B. Comparison of physiological indicators of hardiness acclimation

REL values of lifted seedlings showed significantly different trends over the 2006/7 season at each nursery (Figure 4A). REL for seedlings lifted at Ballintemple nursery was below the suggested hot lift threshold value of 25% for the entire 2006/7 season. In contrast, REL values of seedlings from Killygordon were generally above 25% until the last week of December 2006 (Figure 4A). REL values of seedlings from both nurseries did increase slightly prior to the onset of bud break in early May, but these values were not significantly different to those in measured in late March 2006 (Figure 4).

Comparison of REL compared to $F.LT_{50}$ results in 2006, suggested contrasting hardiness acclimation and lift dates for crops from the different nurseries. These $F.LT_{50}$ results suggest that both the Ballintemple and Killygordon crops were suitably acclimated for lifting and cold storage in late November 2006. In contrast, REL results suggest that the crop from Ballintemple was suitable for cold storage from late September, compared to late December for the Killygordon crop.

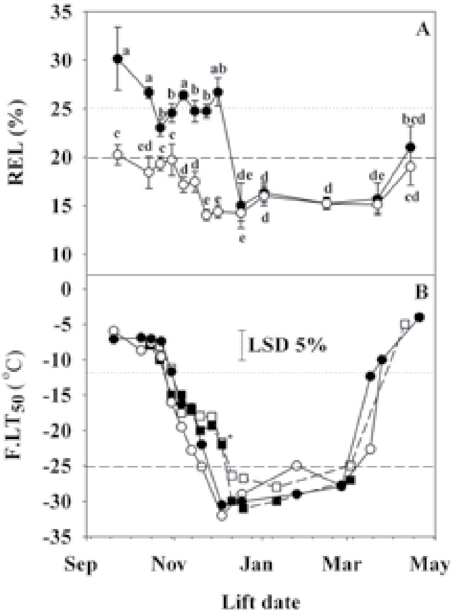

Figure 4: *Cold hardiness development of Sitka spruce at time of lifting from Ballintemple (clear symbols) and Killygordon (black symbols) nurseries for the 2006/7 (circle symbols) and 2007/8 (square symbols) season as determined using REL (2006/7 only, panel A) and F.LT50 assessments (B). All symbols represent a mean and standard deviation (n = 30). REL symbols with different letters are significantly different at p ≤ 0.05. The grid lines across the y axis indicate the suggested % REL and LT50 threshold values for hot lift (dotted lines) and cold storage (broken lines) (after O'Reilly et al 2000, 2002). For panel B, individual error bars could not be displayed because this impeded on the clarity of the presented data. Therefore, LSD error was used to represent the mean error of all the measurements. The asterisk indicates (*) a different lift date for cold storage in the 2006/7 and 2007/8 seasons.*

Estimates of cold hardiness acclimation and de-acclimation, based on $F.LT_{50}$, were similar at both nurseries (Figure 4B). However, the data do show that both crops exhibited different hardening acclimation trends in 2007/8, compared to 2006/7, particularly at the onset of suitability for cold storage (i.e. $F.LT_{50}$ <-25°C). Crops lifted in 2006 were sufficiently acclimated for cold storage by early November, compared to mid-December in 2007. In early December, seedlings were c. 10°C less hardy in 2007 than in 2006 (Figure 4B). The later hardiness acclimation response in 2007, compared to 2006 was associated with the lower accumulated day degree temperature, and particularly the lower cumulative chilling hours experienced in 2007 (Table 2). The number of air frost hours, as indicated by the cumulative chilling hours <0 °C was c. three-fold lower in 2007, compared to 2006.

Table 2: *Inter-annual variations in temperature at nursery sites.*

Year	Nursery	Cumulated day degrees > 5 °C	Cumulated chilling hours < 0 °C
2006	Ballintemple	1,753	31
	Killygordon	1,503	27
2007	Ballintemple	1,552	12
	Killygordon	1,421	9
2008	Ballintemple	1,652	25
	Killygordon	nd	nd
2009	Ballintemple	1,633	56
	Killygordon	nd	nd
2010	Ballintemple	1,489	987
	Killygordon	nd	nd

Experiment 2:

Inter-annual and species variations in dormancy status.

Figure 5 shows the seasonal and inter-annual variation of the different species over six successive seasons for Sitka spruce (SS) and five seasons for the other conifer species (2007 to 2011). For some years, species could not be sampled because crops were lifted for sale at Ballintemple nursery. There were noticeable differences in species dormancy induction responses. Generally, Norway spruce (NS) and Douglas fir hardened off earlier than pine (lodgepole (LP) or Scots pine (SP) species and Sitka spruce (i.e. NS >DF >LP >SP >SS for hot lift). The onset of hardiness sufficient for cold storage is, however slightly different (i.e. NS > SP > LP > SS > DF).

Estimates of cold hardiness acclimation and de-acclimation, based on F.LT50, showed different seasonal trends for lifted crops (Figure 5). The most notable differences occurred in the Sitka spruce crops in 2006/7 and 2010/11. The data show that the Sitka spruce crops exhibited different hardening acclimation trends in 2006/7, compared to 2010/11, particularly at the onset of suitability for cold storage (i.e. LT50 <-25 °C). Crops lifted in 2006 were sufficiently acclimated for cold storage by late December, compared to early November in 2010. In early December, seedlings were c. 10 °C less hardy in 2006 than in 2010 (Figure 5). Ireland experienced the coldest winter in 40 years in 2010, characterised by early onsets of frost and extended period of snow from early December to January. The later hardiness acclimation response in 2006, compared to 2010, was associated with the lower accumulated day degree temperature, and particularly the lower cumulative chilling hours experienced in 2010 (Table 2).

The pattern of cold hardiness acclimation and de-acclimation differed among provenances (Figure 6). Generally, the northern provenances tended to harden off sooner than the more southern provenances. For example, the Oregon (SR) Sitka spruce provenance hardened off about a month later than the QCI provenance.

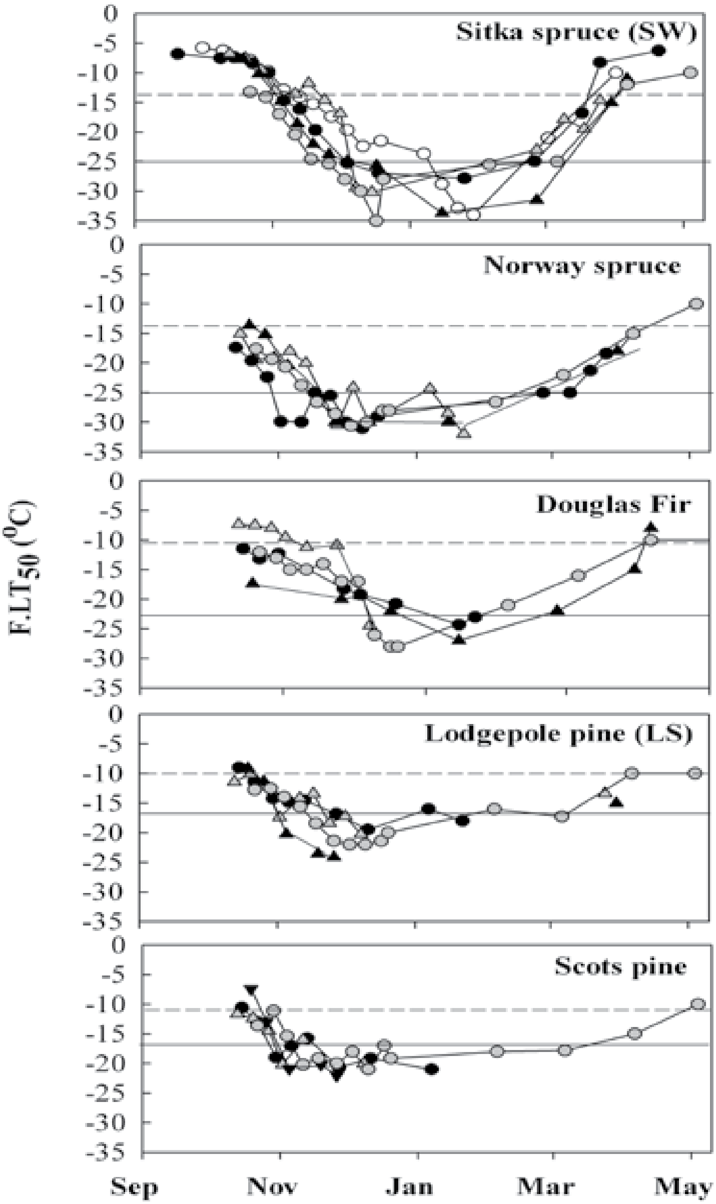

Figure 5: *Seasonal and inter-annual variations in hardiness levels for different species and provenances from 2006 to 2011. Each symbol is a mean value and the vertical bar at top of each graph is the overall error mean square. Symbols for different seasons are 2006/7 (○), 2007/8 (●), 2008/9 (▲) 2009/10 (▲) and 2010/11 (●). Dashed line presents the hot lift threshold and the solid line is the cold store threshold applied at commercial nurseries.*

Experiment 3:

Comparisons of quick indicators of seedling quality during storage

Bare root seedling survival and needle damage was significantly influenced by ambient storage temperature, the presence of water in bags and the duration of incubation following cold storage (Figure 7 and Table 3). Seedlings stored in wet bags and at higher temperatures (10 and 20 °C) deteriorated at a faster rate than those stored in dry bags and those stored at 5 °C (Figure 7). The Fv/Fm was also significantly influenced by ambient storage temperature, the presence of water in bags and the duration of incubation (Figure 8 and Table 3).

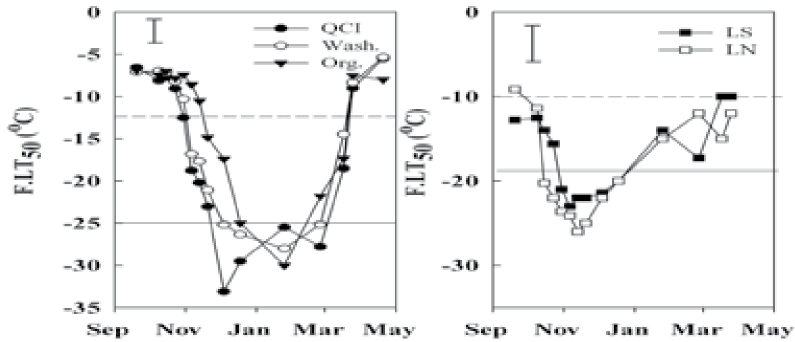

Figure 6: *Seasonal and inter-annual variations in dormancy status for different provenances of Sitka spruce; Washington (SW), Queen Charlotte Island (QCI) and Oregon (SR), Northern (LN) and Southern provenances of Lodgepole pine. All symbols represent a mean value for all years tested (2006-2011). The overall standard error (SE) for all dates is shown, but to improve the clarity of presentation, individual SEs are not shown. Dashed line presents the hot lift threshold and the solid line is the cold store threshold applied at commercial nurseries.*

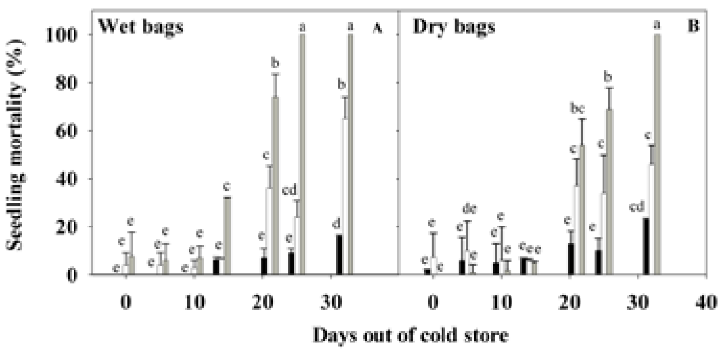

Figure 7: *The effect of bag moisture (dry or wet bags), storage temperature (5 °C (■), 10 °C (□) and 20 °C (■)) and storage duration on seedling mortality following removal from cold storage. Histograms and error bars represent a mean and standard deviation of 3 replicate sample bags (10 seedling samples per bag). Histograms with different alphabetical letters are significantly different at p ≤ 0.05.*

Table 3: *Sources of variation of different physiological parameters, expressed as F-ratios, for the three different storage temperatures, bag treatments (wet and dry) and storage durations.*

Variable	Treatment			Interactions			
	Storage duration (D)	Incubation temperature (T)	Wet/Dry treatment (W)	D × T	D × W	T × W	D × T × W
Mortality	36***	25**	4*	8**	5*	3*	6*
Needle damage	78***	34**	9**	14**	7**	5*	12*
REL	2	5*	<1	2	<1	<1	<1
Fv/Fm	49***	29**	5*	16**	5*	10*	7*
Ethanol	3*	4*	<1	<1	<1	<1	<1
Ammonia	<1	<1	<1	<1	<1	<1	<1

F-ratio with an asterisk was significant at * $p \leq 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$.

Chlorophyll fluorescence appeared to be the best predictor of mortality and seedling deterioration during storage after removal from cold storage. There was a significant correlation ($p \leq 0.001$) between seedling mortality and estimates of maximum, dark-adapted, quantum efficiency (Fv/Fm) of shoots (Figures 7 and 8). In contrast, seedling mortality was not significantly correlated ($p > 0.1$) with REL values or volatile compound concentrations in the airspace of stored bags (Figure 7 and 8). The pattern of REL response varied with storage treatment. REL for those stored at the low temperature (5 °C) stayed about the same or decreased during storage. For seedlings stored at higher temperatures, REL increased slowly or decreased during the early storage period, but values increased towards the end of the storage period. REL increased more quickly in seedlings stored under wet conditions. Volatile ethanol concentrations in the stored bag air space were influenced by storage duration and temperature (Table 3), but concentrations varied and were erratic over the duration of the experiment. Ammonia was detected in stored bags on two occasions only.

Discussion

Quick detection of seedling quality deterioration in warm storage

We demonstrate that assessments of maximal potential quantum efficiency (Fv/Fm) can provide a robust indicator of seedling quality following storage (see Figure 9). The equipment is portable, easy to use and numerous measurements can be taken within a 30 min following an initial dark adaptation period. A major limitation regarding the use of this technology in the past was the prohibitive cost. However, low cost portable fluorimeters are now available for c. €2,000 depending on manufacturer and functionality. Fv/Fm values below 0.6 are generally associated with about 20 to 25%

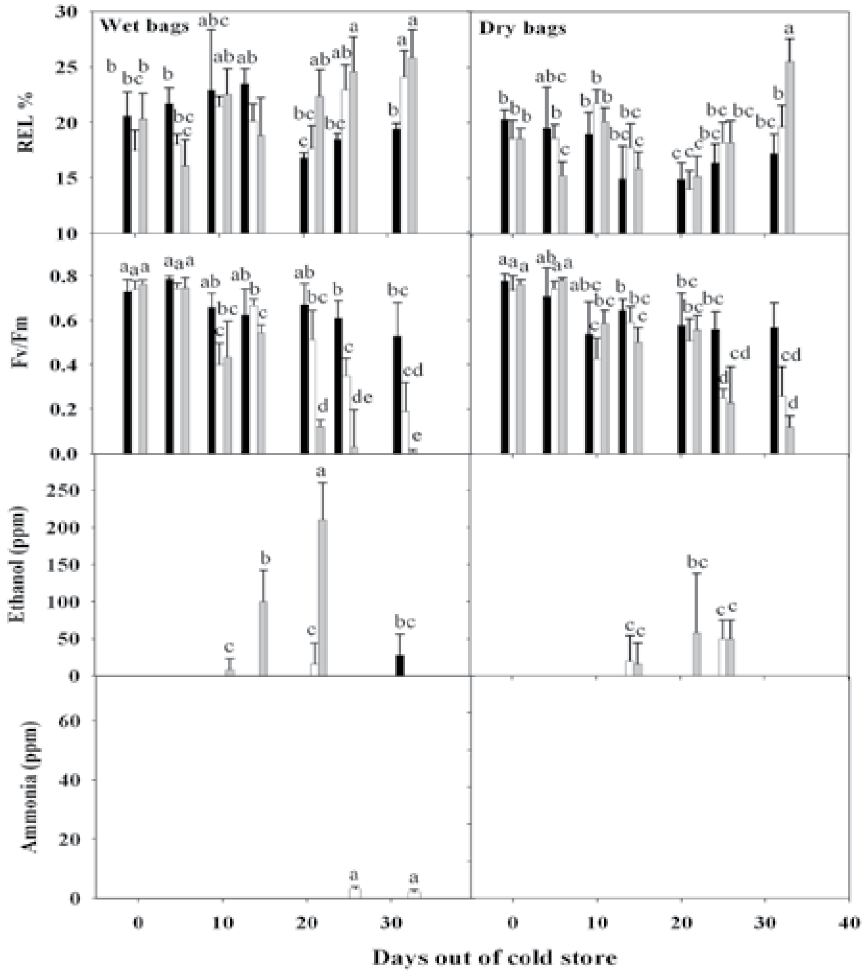

Figure 8: *The effect of bag moisture (dry or wet bags), storage temperature (5 °C (■), 10 °C (□) and 20 °C (■)) and storage duration on root electrolyte leakage (% REL), shoot maximum potential quantum yield (Fv/Fm), volatile ethanol and ammonia concentrations following removal from cold storage. Histograms and error bars represent a mean and standard deviation (n=10 per rep) for REL and Fv/Fm determinations). Means with the same letters are not significantly different at p ≤0.05.*

mortality in bare root Sitka spruce stock that has grown under close to ideal climatic conditions after planting. This threshold is consistent with other recommended Fv/Fm thresholds for seedling survival of conifer species (Perks et al. 2001, Black et al. 2005; Colombo 2005). However, the relationship between Fv/Fm and mortality can vary considerably depending on climatic conditions following out-planting (Black et al. 2005) and seedling morphological condition such as shoot height or shoot to root ratio (O'Reilly and Keane, 2002).

The reliance on a single measure of seedling quality may not be advisable (Puttonen 1996), so the REL technique and a volatile compound accumulation were also assessed. Contrary to expectation, there was no relationship between seedling survival and REL in response to warm storage stress. Similar results have been reported for Douglas fir (Harper and O'Reilly, 2000) and oak (Carbral and O'Reilly 2005). The observed REL trends for warm stored seedlings following removal from cold storage followed a tri-phasic pattern (see Figures 4 and 8); 1) an initial increase due to deterioration of membrane function and higher metabolic activity after removal from cold store (Mc Kay, 1992; Harper and O'Reilly, 2000); 2) followed by a decline in REL after 10 days possibly due to the exhaustion or redistribution of electrolytes in the plant (as suggested by Carbral and O'Reilly, 2005) and 3), a subsequent loss of membrane permeability/integrity or root cell lyses and release of metabolites and ions required cell maintenance after prolonged storage resulting in high REL values after extended storage (20 to 30 days). Black et al. (2008) suggest the use of a combined quality index using both physiological (e.g. Fv/Fm and REL) and morphological parameters (e.g. shoot to root ratio and sturdiness) when assessing stored seedling suitability for out planting. These authors have demonstrated in field trials that combined quality indices correlate better with field survival following out planting than estimates based on a single parameter.

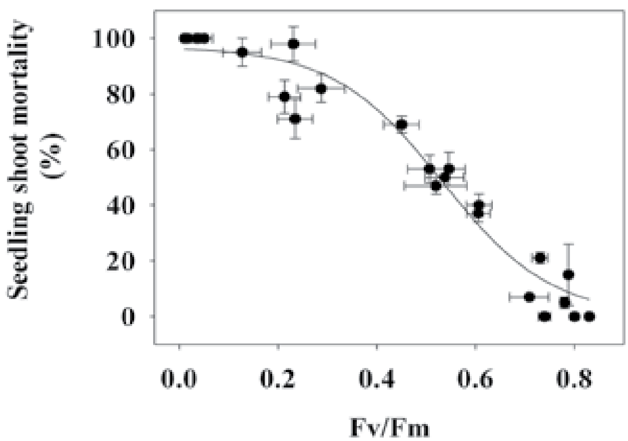

Figure 9: *The relationships between mean fluorescence (Fv/Fm) and mortality of Sitka spruce seedlings, grouped (n = 30) over all sample dates during the storage experiment (experiment 3). Symbols correspond with data as shown in Figures 1 and 2 (r^2 = 0.96, SEE = 7.9). All partial coefficients and the overall regression coefficient were significant at p ≤0.001).*

This paper also reports on the development of an on-site test for seedling deterioration in co-extruded bags following dispatch to site. Although it was possible to detect ethanol and ammonia in the bag air space, these trends were also not consistent with seedling mortality, underlying the weakness of this technique. We suggest this technique does, however, offer potential if the following technical difficulties can be overcome. Firstly, loss of air from the bag head space during handling or puncturing of bags results in the loss of volatile stress compounds. Secondly, compounds such as ethanol can be further metabolised to other end-products, perhaps explaining the responses shown in Figure 8. Finally, the detection limit of the Gastec tubes may be too low for the detection of ammonia. A possible solution to these technical problems, and an avenue worth investigation, may involve the use of Gastec Dosi-tubes (Gastec Corporation, Ayase City, Japan), which can be placed in bags at packaging to detect low levels of stress type compounds over long time periods (2 to 3 days).

Rapid establishment of lifting windows

There was good agreement between the modified freeze tolerance methodology (F.LT_{50}) and traditional visual LT_{50} technique. Seasonal hardening acclimation trends observed for Sitka spruce using the rapid F.LT_{50} technique over the 2006/7 and 2007/8 seasons (Figure 4B), were similar to those reported for Sitka spruce (Washington and Oregon origins) from Ballintemple nursery for the periods 1992 to 1995 (O'Reilly et al. 2000) and for QCI lifted in the U.K. (Cannell et al. 1990), using conventional LT_{50} and other physiological methods.

The methodology described in this paper can be implemented in operational nurseries to provide a rapid assessment of hardiness acclimation for establishment of suitability for lifting operations. Routine testing of Sitka spruce and other conifer species has been implemented at Ballintemple nursery since October 2007. The advantage of this technique over other assessments of hardiness acclimation is that results are available within 3 days, compared to 14 days for the root growth potential or conventional visual assessments of cold hardiness. Furthermore, the method is cheap since it involves use of domestic freezers to generate freeze profiles.

Whilst there are other alternatives to the F.LT_{50} approach for estimating dormancy status under operational conditions, few are robust or rapid enough to be routinely used in an operational context. Recent developments in cDNA based techniques (for review see Howe et al. 2003, Thomashow 1999) have resulted in the launch of a commercial service (e.g. Nsure; www.afsg.wur.nl) that can provide and independent measure of cold tolerance within 2 days of sample receipt, but it might take another 1-2 days for the samples to reach the laboratory after dispatch from nursery. Cheaper and rapid microscopic assessment of mitotic index (Grob and Owens 1994, O'Reilly

2000) and REL (McKay 1993, O'Reilly et al. 2000), have been used to determine safe lifting "windows" but trends were not entirely consistent with other physiological parameters tested in this and other studies (O'Reilly et al. 2000). A possible alternative involves freeze tolerance assessments using REL measurements of thawed shoots (Colombo, 2005). The advantage of this technique is that it could be applied to deciduous species. The downside is that the assay may take 12 to 24 hours longer to perform when compared to the Fv/Fm-based assessment.

A tool for investigating ecophysiological control of hardiness acclimation?

Our data support the view that variations in the physiology of hardiness acclimation from season to season are dependent on climatic factors such as cumulative day degrees >5 °C and cumulative chilling hours <0 °C. These findings are consistent with the findings of O'Reilly et al. (2000), Greer (1983) and Burr et al. (1989). The early stages of hardiness acclimation are thought to be strongly influenced by warm temperatures and photoperiod, while the later stages are believed to be more heavily dependent on low temperatures (Greer 1983; Burr et al. 1989). Other factors (e.g. nutrient and water availability) and the interactions of all factors may also play a role in the hardiness process (Colombo et al. 2001). Different species may display a similar pattern of hardiness acclimation most years, probably because the main drivers (photoperiod and temperature) closely track each other most years. However, some species may respond more strongly to photoperiod than other cues, but differences may be manifested in certain years only. In studies conducted in Ireland for example (O'Reilly et al. 1999, 2000), both Douglas and Sitka spruce sampled from the same nursery showed similar patterns of hardiness development over several years, but differed during a mild autumn. Both species hardened off later during the mild year than in other years, but Douglas fir seedlings did not harden beyond -15 °C for about 5 weeks from late October until early December, which was about the time that chilling temperatures began to accumulate. In contrast, Sitka spruce continued to harden off during this 5-week period. This observation that Douglas fir hardens off initially primarily in response to photoperiod is consistent with previous findings (Burr et al. 1989). Some of the species response difference described in this study may reflect similar ecophysiological response differences. This presents a challenge for nursery operations, especially given that "atypical" patterns of hardening may become more common as a result of climate change. Therefore, more research is needed to elucidate the relationship between these factors and hardiness development, especially the role of chilling and warm temperatures. To this end, the rapid freeze tolerance test, as described in this study, may be useful for the routine characterisation of physiological acclimation in response to different climates.

Acknowledgements

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Survival, early growth and chemical characteristics of *Paulownia* trees for potential biomass production in a cool temperate climate

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Abstract

The results of two experiments to investigate the survival, early growth and chemical characteristics of six Spanish and three Moroccan genotypes of *Paulownia*, grown from container produced and bare root plants, respectively, are described. Both trials were planted in Northern Ireland (NI) and after three growing seasons the overall mean survival and height of the Spanish and Moroccan genotypes were 70.8% and 32.2% and 1.1 m and 2.2 m, respectively. Chemical characteristics, except for nitrogen and ash content, were similar to those reported for other biomass crops such as willow and miscanthus (*Miscanthus × giganteus*). Genotypes that performed well were PWST-33 (*P. fortunei)* from Spain and *P. fortunei* from Morocco. Biomass yields varied significantly (P <0.05) and were considerably lower than those reported for other fast growing species grown as energy crops. The results suggest that the potential of *Paulownia* as an energy crop in NI is limited due to its low performance in biomass production. The main constraints to further planting of *Paulownia* in this region are the edaphic and climatic conditions that pertain, which appear not to be conducive to growth of this tree species.

Keywords: *Paulownia, biomass, energy, cool climate*.

Introduction

There is interest in fast growing tree species for cool temperate climates such as in Britain and Ireland (Leslie *et al*. 2012) as the demand for wood as a renewable source of energy increases across these areas. The European Union (EU) member states have been encouraged to instigate a range of actions detailed in a non-binding Forest Action Plan (FAP) that includes expanding new forest plantings including the use of fast growing species for biomass production (Woods 2008). *Paulownia* is a genus that comprises nine species and a few natural hybrids of such fast growing hardwood trees, that is native to China and has been seen in many countries to offer potential for biomass production (Bergmann 2003, Latorre *et al*. 2011, Yadav *et al*. 2013) due to its sprouting ability and reportedly inherently high energy content (Villanueva *et al*. 2011). Varieties of *Paulownia* have been widely cultivated in China, New Zealand, Australia and the United States where its fast growth habit, wood properties and

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agricultural and environmental uses are highly valued (Wang and Shogren 1992). There is considerable literature on the many industrial uses of *Paulownia* in China, Japan and more recently other Asian countries (Woods 2008). Although it has been reported (Woods 2008) that *Paulownia* has a high flame retardancy due to its low lignin content and peculiar vessel structure, suggesting that its combustion properties might be questionable, the species may also be suitable for pulpwood in suitable niche markets (Olson *et al*. 1989). Though widely planted as an ornamental in the western hemisphere (Woods 2008) little has been reported in the literature regarding its suitability in the cool, moist oceanic climate that exists in Britain and Ireland. Further, it has been shown that *Paulownia* species of differing origin show significant differences in growth rate (Ayan *et al*. 2006, Bergmann 2003).

In the UK and Republic of Ireland, Forestry Departments have developed a long-term strategy for forestry which includes a general increase in forest cover of traditional forestry species planting, that also considers the adoption of fast growing, non- and native species in the search for suitable short rotation forestry (SRF) trees for biomass.

The concept of SRF using *Eucalyptus* and other species has also been investigated in the UK and Ireland, but a longer rotation is required compared with short rotation coppice (SRC) willow (*Salix* spp.) and poplar (*Populus* spp.) crops (Kerr 2011, Wickham *et al*. 2010). Both willow and poplar have been grown as SRC for several decades (Tubby and Armstrong 2002). Willow in particular has been widely planted as a biomass fuel crop, but susceptibility to disease, especially rusts caused by varieties of the *Melampsora* genus, greatly curtails growth and productivity, particularly in mono-culture plantations (McCracken and Dawson 1997), though the development of polyclonal planting systems has been shown to greatly reduce the incidence and severity of rust infestations (McCracken *et al*. 2001). Therefore the search for an alternative fast growing tree species to widen the biomass fuel species resource base is desirable to help meet the growing demand for biomass. This may offer an opportunity for genotypes of *Paulownia* derived from advanced breeding programmes that are current in many countries to develop the species (Woods 2008).

These issues do not however, preclude use of *Paulownia* as a possible biomass genus in the UK and specifically within Northern Ireland (NI). This research work describes the results of screening trials to assess survival, early growth as well as chemical and calorific characteristics of a range of *Paulownia* genotypes for use as a biomass crop in NI.

Materials and methods

Site description

The study site was located on a field previously dominated by perennial ryegrass (*Lolium perenne* L.) on a gentle south to southwest facing slope at Hillsborough about

15 km west of the city of Belfast in NI (latitude 54.48° N, longitude 6.08° W) where, in general the climate is dominated by low pressure Atlantic storm systems which cause cool and humid conditions characterised by an annual average summer and winter temperature of 14.5 °C and 4.5 °C, respectively (Smyth *et al*. 2002). The site was chosen as typical of the type of land that was anticipated would become available for an energy crop. A total of 9 genotypes of *Paulownia* trees which were sourced from two tree nurseries that could only supply their standard commercially available plant material were used for the study. Three genotypes (*P. fortunei, P. elongata × fortunei* and *P. elongata*) of two year-old bare rooted plants were shipped from Morocco and held in a cold room for less than two weeks prior to planting. Seedlings of six other genotypes (PWCOT-2: *P. elongata × fortunei*, PW-105: *P. elongata × fortunei × tomentosa,* PWL-1*: P. elongata × fortunei*, PWCOT-1: *P. elongata*, PWST-33: *P. fortunei* and PWST-11: *P. elongata × fortunei*) that had been produced by tissue culture in Spain (COTEVISA) were shipped to the Agri-Food and Biosciences Institute (AFBI) in NI. These were potted in 3 L containers with a peat-based substrate and grown under controlled conditions for 4 months and subsequently acclimatised for two weeks prior to field planting. Before planting, plants from Morocco and Spain were sorted into similar sizes by height (50 cm) and root collar diameter (7-10 mm) and the plants from the two origins established in two separate but adjacent trials less than 20 m apart in May 2009 with the genotypes within each trial planted in 5 and 4 blocks, respectively, in randomised block designs.

The mean annual temperature between 2009 and 2013 at Hillsborough, the nearest recording station (350 m distant) was 8.9 ºC with maximum and minimum temperatures of 24.6 ºC and -8.4 ºC respectively. Mean annual precipitation was 820 mm and the average wind speed was 2.1 ms^{-1} during the same period. The soil in this area is moderately deep, well drained and loamy overlying basalt rock strata. Soil pH where the material was planted was 5.49 and 5.89, respectively. Though the trials were only a few metres apart, their soil mineral concentration in potassium (K), magnesium (Mg) and phosphorus (P) were markedly different (Table 1).

Before planting, existing vegetation on both sites was sprayed with glyphosate, then ploughed and cultivated (power harrowed) 4 weeks later. Each block within the Spanish and Moroccan trial consisted of 6 and 3 plots, respectively; each plot contained 6 plants planted at a spacing of 1.8 m × 1.8 m. Each planting hole was dug

Table 1: *Mineral concentration of potassium (K), magnesium (Mg) and phosphorus (P) from soil of Spanish and Moroccan genotypes experimental trials.*

Experimental site	K (mg $litre^{-1}$)	Mg (mg $litre^{-1}$)	P (mg $litre^{-1}$)
Spanish genotype trial	1287.6	443.4	20.3
Moroccan genotype trial	445.4	109.8	47.4

40 cm wide and 50 cm deep, then backfilled after planting with extracted soil and a jute mat fixed around the base of each tree to suppress weeds. Single guard rows of spare plants were planted around the plots. An electric fence was erected around both trials to prevent damage by farm livestock and/or wildlife. Residual herbicide (Pendimethalin + Isoxaben) was sprayed across the trials after planting. In both sites, fertiliser (Osmocote, Scott plus, 8-9 months longevity at 200g plant^{-1}) was applied to minimise differences due to soil moisture and nutrient deficiencies. Thereafter the inter-row areas were regularly mowed during the growing seasons.

Assessment

Survival, height and number of shoots were evaluated after three growing seasons in the field. Height from ground level was measured to the nearest 0.1 cm for all trees in each plot using an extendable measuring pole (Senshin, 8 metre). Number of shoots with a minimum diameter of 2 cm were counted. Destructive measurements were also made in 2013 at the end of the third growing season. All trees were felled at ground level and above- ground whole tree fresh weight (FWT) was recorded from a suspended balance (Nagata: 600 kg × 0.2. HJS). Harvested samples from each plot were then prepared for laboratory analysis.

Chemical analysis

All fresh fuel samples were weighed then oven dried at 80 °C for 48 hours for dry matter (DM) assessment (%DM = (dry weight/fresh weight) × 100). The dried samples were milled (Fritsch Pulverisette P25) down to 0.8 mm particle size, sealed and labelled in 200 ml jars. Laboratory analysis of Nitrogen (N) content (g kg^{-1} DM) and carbon (C) (g kg^{-1} DM) was by the Dumas method (Elementar VarioMax CN). Gross energy (GE MJ kg^{-1} DM) was measured by bomb calorimetry (Parr 6300 Calorimeter). Phosphorus (P) and potassium (K) content were determined using standard laboratory methods. Flame oxidation at 550 °C in a Vecstar closed combustor furnace was used to determine ash (g kg^{-1} DM) content and the oven dry matter (OVDM g kg^{-1}) assessed at 101 ± 1 °C in a Gallenkamp oven.

Milled fuel samples (5 mg) were analysed in triplicate for volatile (Vc%) and fixed carbon (FC %) content by heating from room temperature to 950 ºC in nitrogen, which was maintained for 30 minutes in a ventilated oven, before returning to room temperature, using a thermogravimetric (TGA) analyser (Mettler Toledo TGA/DSC1, Switzerland).

Combustion characteristics of *Paulownia* genotypes were also analysed using the same instrument, by heating from room temperature to 600 ºC in air at a heating rate of 20 ºC^{-1} min to assess peak primary weight loss (PWl %), char weight loss (CWl %), peak combustion temperature (PTC °C) and char combustion temperature (CTC °C). Gas flow rates were 50 ml min for all thermogravimetric work.

Statistical analysis
Analysis of variance (ANOVA) was performed on the plot means using Genstat (16th Edition) for survival, height, number of shoots, fresh weight, dry matter and data from chemical analyses. Where diagnostic probability plots of the residuals from the analysis of variance indicated that the data were sufficiently normal with homogeneous variance, the untransformed results were presented and the means were compared using a LSD at P <0.05. Variables such as counts or numbers were transformed by taking the square root and percentages by using angular transformations.

Results

Survival
The percentages of *Paulownia* trees surviving after three growing seasons in both trials are shown in Figures 1 and 2. After three growing seasons, considerable mortality was recorded at the Moroccan origin site with overall average survival rates much lower than the Spanish genotypes. Among Spanish genotypes (Figure 1), PW-105 had significantly (P<0.003) lower survival (20.8%) than all other genotypes and PWST-33 had the highest survival rate (95.8%) followed by PWCOT-1 (87.5%). Slightly lower rates were seen in PWCOT-2, PWL-1 and PWST-11 in decreasing order (Figure 1).

Survival of trees of Moroccan origin ranged from 30% to 33.3% (Figure 2) but these differences were not statistically significant.

Growth
The average heights, number of shoots, total fresh weight (TFW) and dry mass (DM%) of Spanish and Moroccan *Paulownia* trees in 2013, after three growing seasons are shown in tables 2 and 3. Among Spanish genotypes, PW-105 was significantly (P <0.007) smaller (0.4 m) than other genotypes and PWST-33 and PWCOT-1 were the

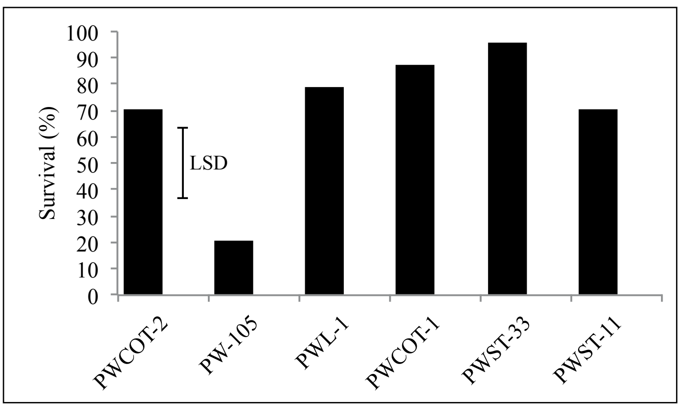

Figure 1: *Percentage survival of Spanish genotypes, three growing seasons after establishment at Hillsborough, Northern Ireland (LSD = least significant difference at the 5% level).*

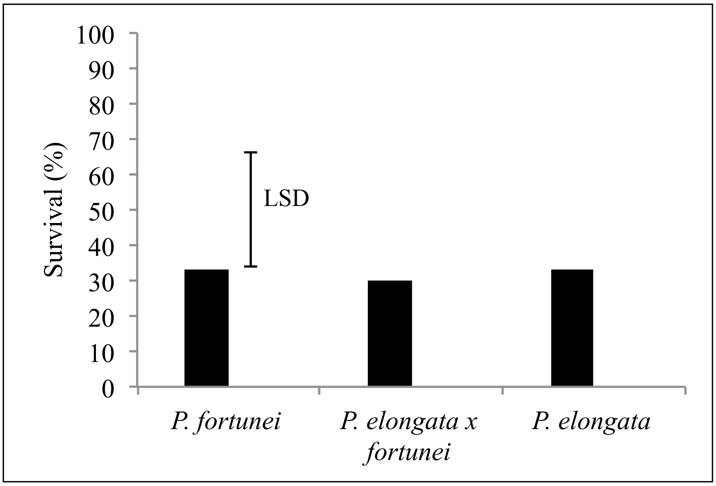

Figure 2: *Percentage survival of Moroccan genotypes, three growing seasons after establishment at Hillsborough, Northern Ireland (LSD = least significant difference at the 5% level).*

tallest (1.5 m). Genotypes PWCOT-2, PWCOT-1 and PWST-33 had significantly more shoots (7.4, 7.5 and 9.0 respectively) than the rest of genotypes and PW-105 had the fewest (2.1). Genotype PW-105, had significantly (P <0.001) lower TFW and greater DM than other genotypes whereas PWST-33 yielded the highest amount of fresh biomass.

Growth variables among Moroccan genotypes did not differ significantly (Table 3). However, overall average heights varied by 48% between the tallest and shortest genotypes (*P. fortunei* and *P. elongata,* respectively). All three genotypes had similar number of shoots per plant (4.5) though *P. fortunei* had more TFW and higher DM% than the other two genotypes.

Chemical characteristics

Tables 4 and 5 show chemical characteristics of *Paulownia* from both origins. The concentration of C among Spanish genotypes (Table 4) ranged from 482.9 to 493.2 g kg DM and the genotype PW-105 had significantly (P <0.001) higher C content than other genotypes. Nitrogen also was significantly higher (P <0.001) in PW-105 than all other

Table 2: *Average height, number of shoots, total fresh weight (TFW) and dry mass (DM%) of Spanish* Paulownia *genotypes after three growing seasons in the field at Hillsborough, Northern Ireland.*

Variable	PWCOT-2	PW-105	PWL-1	PWCOT-1	PWST-33	PWST-11	LSD
Height (m)	1.0	0.4	1.1	1.5	1.5	0.9	0.56 **
Shoots (N°)	7.4	2.1	4.6	7.5	9.0	4.8	2.76 ***
TFW (kg)	9.6	0.9	9.3	19.0	23.7	12.6	7.32 ***
DM (%)	37.2	44.1	37.6	34.4	34.7	32.6	5.50 **

Note: ** = p <0.01, *** = p <0.001, LSD least significance at the 5% level.

Table 3: *Mean height, number of shoots, total fresh weight (TFW) and dry mass (DM%) of Moroccan* Paulownia *genotypes after three growing seasons in the field at Hillsborough, Northern Ireland.*

Variable	*P. fortunei*	*P. elongata × fortunei*	*P. elongata*	LSD	
Height (m)	3.0	2.1	1.6	2.44	NS
Shoots (N°)	4.5	4.5	4.5	3.59	NS
TFW (kg)	26.4	15.2	2.6	31.66	NS
DM (%)	48.1	42.4	43.4	14.32	NS

Note: NS = not significant, LSD least significance at the 5% level.

genotypes and PWST-33 had significantly lower N concentration than all other genotypes except for PWCOT-1. All Spanish genotypes had similar ash content. There were small differences in P and K among Spanish genotypes with PWST-11 having significantly higher P content than PWST-33 and significantly higher K content than all other genotypes. The PWST-33 contained significantly ($p < 0.002$) less P than the other genotypes. Genotype PW-105 had lower K than other genotypes. The OVDM and GE ranged from 928.7 to 934.9 g kg^{-1} DM and 19.3 to 20.0 MJ kg^{-1} DM, respectively and were statistically similar among these genotypes (Table 4).

For Moroccan genotypes (Table 5) only the OVDM showed significant difference ($P < 0.002$) due to *P. fortunei* having a significantly higher OVDM than the hybrid, though the actual difference was very small (<1.00% of weight) and *P. elongata* had significantly ($P < 0.05$) less OVDM% than the other two genotypes. Overall the averages of C, N and ash were 486.8, 5.3 and 16.1 g kg^{-1} DM, respectively and differences among genotypes were not significant (NS). Content of P and K in the stems did not show statistical differences, but *P. fortunei* had much lower content of these minerals (19.0 and 17.2% respectively). Mean GE between Moroccan genotypes was similar, ranging only from

Table 4: *Average amount of C, N, ash, P, K, oven-dry matter (OVDM), gross energy (GE), volatiles and fixed C in the stems of Spanish genotypes after three growing seasons in the field at Hillsborough, Northern Ireland.*

Variable	PWCOT-2	PW-105	PWL-1	PWCOT-1	PWST-33	PWST-11	LSD	
C (g kg^{-1})	483.6	493.2	486.1	484.7	482.9	486.0	4.07	***
N (g kg^{-1})	6.7	8.0	6.7	6.2	5.7	7.0	0.84	***
Ash (g kg^{-1})	22.6	22.4	21.8	21.0	17.6	24.9	4.32	NS
OVDM (g kg^{-1})	930.7	928.7	933.6	934.9	934.8	932.6	4.80	NS
P (mg kg^{-1})	846.0	791.0	838.0	817.0	673.0	866.0	111.20	*
K (mg kg^{-1})	5921.8	4611.5	5802.1	5990.3	5,318.7	7,366.9	1,268.39	**
GE (MJ kg^{-1})	19.6	20.0	19.6	19.3	19.4	19.3	0.50	NS
Vc %	76.3	75.2	76.9	76.6	77.6	76.3	1.11	**
FC %	14.0	14.6	13.6	13.7	13.0	13.9	0.71	**

Note: * = $p < 0.05$, ** = $p < 0.01$, *** = $p < 0.001$: NS = not significant, LSD least significance at the 5% level.

Table 5: *Mean amount of C, N, ash, P, K, oven-dry matter (OVDM), gross energy (GE), volatiles and fixed C in the stems of Moroccan genotypes after three growing seasons in the field at Hillsborough, Northern Ireland.*

Variable	*P. fortunei*	*P. elongata × fortunei*	*P. elongata*	LSD
C (g kg^{-1})	485.9	484.8	489.8	5.02 NS
N (g kg^{-1})	4.5	5.2	6.1	1.77 NS
Ash (g kg^{-1})	12.6	16.9	19.0	6.86 NS
OVDM (g kg^{-1})	939.9	939.4	933.8	4.24 *
P (mg kg^{-1})	600.0	782.0	794.0	277.40 NS
K (mg kg^{-1})	3,743.5	5,261.8	5,246.8	2,585.38 NS
GE (MJ kg^{-1})	19.6	19.6	19.8	0.18 NS
Vc %	78.1	78.1	77.7	2.11 NS
FC %	13.6	14.0	13.5	1.35 NS

Note: * = p <0.05; NS = not significant, LSD least significance at the 5% level.

19.6 to 19.8 MJ kg^{-1} (Table 5). The analysis also revealed (Table 4) that, among Spanish genotypes, there were small (<2.0%) but significant differences (p <0.01) in fixed C (carbon not released with volatiles) while differences were not significant (NS) among Moroccan genotypes (Table 5).

Thermo-gravimetric results

Distinct differences in thermo-gravimetric properties were observed (Table 6 and 7) within genotypes of Spanish origin. Some genotypes, for example PWL-1, PWCOT-1 PWST-33 and PWST-11 (Table 6), had a higher weight loss relative to the phase of combustion, compared to PWCOT-2 and PW-105 which decomposed only when temperatures exceeded 333 °C. However, PW-105 had a significantly higher (467 °C) char combustion temperature than the other genotypes, which appeared to be related to its high DM (Table 2) and fixed C (Table 4) contents.

There were no significant differences (NS) in any of the thermogravimetric variables among the Moroccan genotypes (Table 7).

Table 6: *TGA combustion analyses (peak primary weight loss; PWl %, char weight loss; CWl %, peak combustion temperature; PTC °C and char combustion temperature; CTC °C) results for Spanish* Paulownia *genotypes after three growing seasons in the field at Hillsborough, Northern Ireland.*

Variable	PWCOT-2	PW-105	PWL-1	PWCOT-1	PWST-33	PWST-11	LSD
PWl %	62.4	61.7	64.3	63.2	64.1	63.3	1.69 *
CWl %	28.2	28.5	26.8	27.3	26.7	27.2	1.29 *
PTC °C	333.2	332.6	333.0	333.9	334.2	332.1	1.64 NS
CTC °C	459.4	467.5	458.1	459.7	456.3	453.6	6.18 *

Note: * = p <0.05, ** = p <0.01: NS = not significant, LSD least significance at the 5% level.

Table 7: *TGA combustion analyses results (peak primary weight loss; PWl %, char weight loss; CWl %, peak combustion temperature; PTC °C and char combustion temperature; CTC °C) for Moroccan* Paulownia *genotypes after three growing seasons in the field at Hillsborough, Northern Ireland.*

Variable	*P. fortunei*	*P. elongata × fortunei*	*P. elongata*	LSD
PWl %	65.1	65.7	63.7	2.84 NS
CWl %	27.0	26.3	27.4	2.02 NS
PTC °C	335.1	333.9	333.4	3.69 NS
CTC °C	459.9	457.5	461.2	4.06 NS

Note: NS = not significant, LSD least significance at the 5% level.

Discussion

Survival

Survival among Moroccan genotypes was low. Survival also varied considerably among Spanish genotypes. Survival of Moroccan genotypes was lower than among Spanish genotypes but origin was confounded by differences in type of nursery stock, aspects of climatic and soil conditions. Some of the differences may have been partly due to the Spanish genotypes having been established as containerised plants with well-developed root systems and fertiliser application in the greenhouse which increased nutrient availability in this soil. This observation would support the idea that containerised plants would have an advantage compared to bare rooted plants in harsh environments (Bergmann 1998), although differences in survival are less likely to be associated with ability to form roots than the capacity of plant tissue, especially growing points, to withstand a cool oceanic climate. Although *Paulownia* has been reported to withstand a temperature of -20 °C (Barton *et al*. 2007), a likely reason for the severe reduction in survival of Moroccan plants may have been the exceptionally cold winters during 2010 and 2011 with minimum temperatures of -14 °C and -7.2 °C respectively, registered at Hillsborough. Some genotypes suffered more damage from early or late frost while other varieties survived at temperatures down to -8 °C which suggests that, as for other fast growing such as eucalyptus and poplar species in the UK, freezing conditions present a hazard (Cope *et al*. 2008).

Although *Paulownia* has been reported to grow on a wide range of soils (Wang and Shogren 1992, Barton *et al*. 2007) it has also been reported (Lyons 1993) that sandy, volcanic and deep alluvial soils are more suitable than untreated heavy clay soils as the latter prevent drainage and impede root growth. However soil type, nutrient availability (Table 1) and pH were within the reported range of suitability for *Paulownia* (Woods 2008). Barton *et al*. (2007) suggest that *Paulownia* can grow quite satisfactorily on soils as low as pH 5.0 but for optimum growth it should be between pH 6.5 and 7.0.

Water availability is not a limiting factor in NI, with an average annual rainfall of

820 mm that is generally evenly distributed. Excessive soil moisture may inhibit deep rooting in *Paulownia,* as has been shown for other tree species grown in the UK and Ireland (Paterson and Mason 1999). Barton *et al*. (2007) and Woods (2008) mention that the water table should be at least 1.5 m below the surface. However, soils of both trials in this study were rotovated to improve drainage. Infections by pests and/or pathogens were not observed on any of the trees on the sites and so disease was unlikely to have been a cause of any mortality.

Paulownia does not have a high tolerance to strong winds (Woods 2008) and this might have been another factor affecting survival and growth. Strong winds and exposure have been the most limiting factors to height growth of trees species introduced into Britain and Ireland (Macdonald *et al*. 1957, Savill 1974). Experience in New Zealand (Barton *et al*. 2007) have shown that the breakage of young stems and branches of *Paulownia* trees can occur when wind speed exceeds 40 km $hour^{-1}$. Similar effects might have occurred in this experiment as the average wind speed was 2.1 m s^{-1} and winds of over 40 km $hour^{-1}$ were recorded at the Hillsborough weather station on several occasions between 2009 and 2013. Other authors (Lyons 1993, Bergmann 2003) have reported survival problems in areas with persistent winds due to the susceptibility of *Paulownia*'s large juvenile leaves to wind damage. Though not directly comparable, it was observed that average survival of Spanish genotypes (with the exception of PW-105) grown from container-grown plants were almost 40 percentage points higher than the mean survival of the Moroccan genotypes in the adjacent trial, but were raised as bare root plants.

Growth

Two of the Moroccan genotypes, *P. fortunei* and *P. elongata x fortunei*, were considerably taller than the Spanish genotypes and *P. fortunei* also had the highest total fresh weight (26.4 kg) and the Spanish PW-105 the lowest (0.9 kg). In general, Moroccan *Paulownia* genotypes were taller than Spanish ones after three growing seasons, but with a much lower survival rate. *Paulownia* growth is generally very dependent on site conditions and tree age (Wang and Shorgen 1992) and growth is most rapid during the year following planting year and subsequent to cutting back (Barton *et al*. 2007). Although the trees were planted at wider spacing (1.8 m × 1.8 m) than SRC willow would be planted (but still narrower compared to other potential SRF tree species), the *Paulownia* trees in this study were generally shorter than those reported for other energy crops in Britain and Ireland (Kerr 2011, Neilan and Thompson 2008). *Salix* spp. in NI, although planted at higher density, can reach over 7 m in 3 years (Dawson 2007). *Populus* spp. when planted at similar spacing can reach 7 m in height and in the south of England plants can reach a height of 2 m in the first season (Jobling 1990).

The results from this study show that *Paulownia* trees grew much more slowly under NI conditions than at Mediterranean and subtropical latitudes (Bergmann 2003, Duran-

Zuazo *et al*. 2013). Wang and Shorgen, (1992) reported that the average height of a 7 year-old *Paulownia* tree is about 8-12 m in China. In the US (Bergmann 2003) with air temperature ranging from 24 ºC to 30 ºC and in more southerly light conditions, two year-old *P. tomentosa,* coppiced in the first year, reached an average height of 4.3 m. These high temperatures and light levels are necessary to achieve potential growth (Lyons 1993, Barton *et al*. 2007), but in NI levels of light are generally lower with relatively few days of clear skies (Smyth *et al*. 2002) which may also have affected tree height growth.

Regarding biomass production, Yadav *et al*. (2013) reported that under favourable conditions the harvestable biomass of *P. elongata* is 92 kg per tree after three growing seasons. Assuming that *Paulownia* trees from both origins were planted at 3,086 trees ha^{-1} in NI, the yield of *P. fortunei*, *P. elongata* × *fortunei* and *P. elongata* would range between the equivalent of 6.6, 3.4 and 1.9 t DM ha^{-1} yr^{-1}, respectively. In the best case scenario, this is ~55% less than the average yield of conventional SRC willow in NI (Dawson 2007) but relatively similar to other potential SRF tree species tested in Britain and Ireland, except for *Eucalyptus* which yields about 10 t DM ha^{-1} yr^{-1} (Kerr 2011, Neilan and Thompson, 2008). On the other hand, despite the high survival of Spanish genotypes (Figure 1), the mean annual yield of just over 4.2 t DM ha^{-1} yr^{-1} for the most successful Spanish genotype (PWST-33) would not be comparable with the poorest willow yield of 7 t DM ha^{-1} yr^{-1} in NI (Dawson 2007). An important factor in these yields was the hollow stems of juvenile growth, observed during harvest, samples of which are illustrated in Figure 3. The void area accounted for at least 1/4 of the total transverse area in the mid and upper sections in two year old stems, though these voids reduce during the third growing season. However, biomass production from these two trials should be treated with some caution given that they are extrapolated from small scale experiments with a small number of trees per plot.

Kerr (2011) reported that species such as alder, ash (*Fraxinus excelsior* L.), birch (*Betula* spp.) and sycamore (*Acer pseudoplatanus* L.) have potential in Britain for SRF

Figure 3: *Transverse sections (left to right) of a 3-year-old harvested stem showing basal (3 years old), mid-section (2 years old) and upper section (1 year old) growth. Note that the stem void area decreases as the tree matures.*

to yield between 5.0 and 7.4 t DM ha^{-1} $year^{-1}$ on a 20-year rotation. Woods (2008) pointed out that *Paulownia* in Georgia in the US can produce 8.4 t DM ha^{-1} in 16 months and Duran-Zuazo *et al*. (2013) reported that *Paulownia* in Spain can provide an average biomass yield of 10.6 t DM ha^{-1} in 24 months. Nevertheless the prediction made by Woods (2008) from a literature review assessment of its potential as a biomass crop, that *Paulownia* trees planted in NI would yield 15 t DM ha^{-1} of biomass yield after three years, is not supported by the results in this study.

Dry matter content of freshly harvested wood varies considerably depending on species, age and time of year and is an essential factor for energy efficiency of potential biomass crops (Forbes *et al*. 2014). Most Spanish genotypes had about 10% lower DM content than those reported for willows and miscanthus cultivated in NI (Dawson 2007, Easson *et al*. 2011), however DM of Moroccan genotypes were more similar. In general *Paulownia* has a DM of 40% when planted in different climatic conditions such as US and Spain (Woods 2008, Latorre *et al*. 2011).

Overall, the genotypes from Spain showed a tendency to produce more shoots than the other genotypes. Although it is strongly recommended (Young pers. comm.[1]) that *Paulownia* trees should be cut back to ground level to promote the formation of new shoots during the second year when trees reach a minimum diameter of 7 cm, this operation was not carried out in this study as trees did not reach that threshold. This practice is also recommended for SRC crops such as willow and poplar in Britain and Ireland to encourage the formation of multi-stemmed stools in the following growing season (Tubby and Armstrong 2002, Wickham *et al*. 2010). It has been reported (Lyons 1993) that *Paulownia* trees can produce 1 to 6 shoots after cutting back following the first year to induce new coppice growth. The early assessment in these trials in NI showed that the numbers of primary shoots is a key component of the growth pattern of *Paulownia* from both origins and its potential use as an energy coppice crop. Willow crops produce on average one to three shoots after the first growing season and poplar 1 or 2 shoots and both species produce multiple stems after being cut back (Tubby and Armstrong 2002, Dawson 2007). Spanish and Moroccan *Paulownia* genotypes produced an average of 6 and 4.5 shoots, respectively, after three growing seasons which would show some potential for coppicing, although it would need to be examined further.

Chemical characteristics

In general there are several factors such as storage and processing that affect the chemical characteristics of biomass crops (Forbes *et al*. 2014). Despite there being large statistical differences in growth characteristics of Spanish varieties, overall the chemical characteristics were similar to those reported for other energy crops including *Paulownia* (Cuiping *et al*. 2004, Latorre *et al*. 2011, Forbes *et al*. 2014) except for N and ash content.

[1] Mr Nigel Young, World Paulownia Europe Ltd, England. 2009.

Forbes *et al*. (2014) reported that within a group of six biomass fuels, willows had the highest content of N (5.7 mg kg^{-1}) which is lower than that found for *Paulownia* in this study (Tables 6 and 7). Ash content of *Paulownia* also appears to be much higher than those reported for *Paulownia* (Cuiping *et al*. 2004) and other fuel crops (Forbes *et al*. 2014). The ash content of *Paulownia* in this study ranged from 17.6 to 22.6 (g kg^{-1}) compared to 5.3 (g kg^{-1}) reported by Cuiping *et al*. (2004) which would suggest that the high N content played a key role in the ash-forming content of these young *Paulownia* trees. Latorre *et al*. (2011) also reported high contents of ash in three *Paulownia* species with high contents of carbonates and chlorates which are undesirable in biomass fuels.

Gross energy from *Paulownia* (Tables 4 and 5) was within the reported range of other biomass material (Forbes *et al*. 2014), particularly willows and miscanthus but was lower than *Pinus*, spruce and forest brash. The fixed carbon which is the residual fraction from pyrolised fuel after deducting ash (Villanueva *et al*. 2011) was also similar to those reported by Forbes *et al*. (2014), suggesting that *Paulownia* might be a suitable fuel. *Paulownia* from both origins (Tables 4 and 5) exhibited higher volatile content than other biomass fuels (Forbes *et al*. 2014), indicating a greater amount of hemicelluloses.

Regarding the thermo-gravimetric behaviour of *Paulownia*, the results showed that the degradation of *Paulownia* follows a closer pattern to willows, wood pellets and conifer material than miscanthus (Forbes *et al*. 2014). However, Villanueva *et al*. (2011), stated that *Paulownia* would exhibit less resistance to the increase in temperature compared to poplar, *Eucalyptus* and *Pinus*. In this study the temperature of degradation was similar to that reported by Villanueva *et al*. (2011) for 5-7 year-old *Paulownia* trees. Further, between the genotypes the percentage weight loss (PWL %) over time displayed similar patterns and the weight loss curves of the mean values for genotypes of both trials were almost identical (Figure 4).

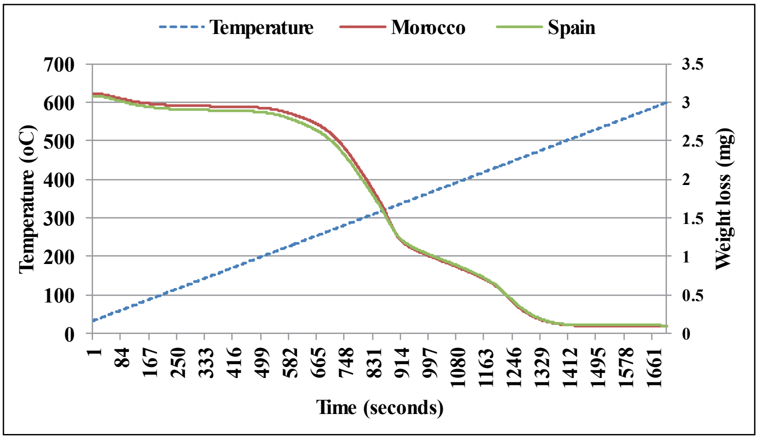

Figure 4: *Thermogram of the mean percentage weight loss (mg) of the Spanish and Moroccan genotypes.*

Conclusions

Survival and growth of *Paulownia* trees in NI could have been restricted by a range of factors including heavy soils and the cool, moist, wet and windy oceanic climate. Survival was satisfactory only for Spanish genotypes suggesting that these were more tolerant of the NI climate than Moroccan genotypes but *Paulownia* is still unlikely to be suited for general planting. The results re-iterate that the introduction and adoption of exotic tree species for either biomass or conventional forestry and their out-planting performance is a complex interaction of many factors, including origin, planting stock and climate.

The chemical characteristics of *Paulownia* trees in this study indicate their suitability for use as a biomass fuel, except for the high contents of N and ash which might have been as a result of a high proportion of juvenile material. Longer growing terms might increase their suitability for operational use.

Paulownia is already grown widely in a range of situations in Mediterranean, tropical and subtropical climates and its wood is a useful raw material for producing biomass fuel; however, the data in this study indicated that growth in NI is far from optimal. There is no clear evidence for their potential use in cool temperate climate and further information is required on performance of these and other genotypes on a wide range of sites. Although the findings cannot be generalised to the whole of Britain and Ireland, where some areas are warmer and sunnier than NI, the use of *Paulownia* as a potential biomass crop in NI appears to be limited and further research is required to provide long-term information on its field performance.

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A review of stumping back and case study of its use in the rehabilitation of poorly performing pole-stage sycamore

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Abstract

First rotation broadleaf plantations present a range of inherent challenges to the achievement of good form and vigour. Where biotic and/or abiotic factors compromise early growth and stem quality, appropriate management interventions to improve these are required. An historical review of "stumping back" literature is presented together with a case-study. The B-SilvRD broadleaf silviculture research project includes a "rehabilitation" strand, whereby innovative measures to improve poorly performing stands of commercial broadleaves are being trialled. One such pilot trial involves a 17year-old sycamore (*Acer pseudoplatanus* L.) plantation, which had not performed well and required significant intervention to improve its silvicultural and economic viability. This paper reviews the literature on stumping back and presents a case-study with results of three different line thinning/stumping back treatments, including analysis of different light regimes and the impact of light levels on coppice regrowth.

Keywords: *Broadleaf, silviculture,* Acer pseudoplatanus*, coppice.*

Introduction

Ireland's current forest resource has largely been created through state-funded afforestation in the last century, which has seen over 720,000 ha of new plantation forest established since the 1920's. Due to the relatively poor quality land available for afforestation, together with the need to develop an economically-viable timber resource, the national planting programme up until the 1980s was based almost entirely on fast growing exotic conifer species. During the eighties there was a realisation of the need to widen the species base (COFORD 2012). Since state support for forestry development in the private sector began in the early eighties, over 60,000 ha of new broadleaved plantations have been established (Hendrick and Nevins 2003, Forest Service 2012). More than 9,000 ha of sycamore (*Acer pseudoplatanus* L.) are present in Ireland, approximately 5% of the broadleaf forest estate (Forest Service 2013). Unlike the established conifer forest, broadleaves have proven to be much less suited to the challenging first rotation conditions inherent in green field sites. Exposure, soil conditions, low intra-specific species competition due to relatively low stocking densities, high light levels and weed competition are all

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aspects of the open, green field environment which present particular impediments to broadleaf crop quality (Hawe and Short 2012). Add to this the potential pitfalls of species selection, provenance selection and availability, ground preparation and a range of post-planting biotic and abiotic challenges and it is hardly surprising that first rotation broadleaf woodlands in Ireland are sometimes compromised in terms of vigour and, more often, stem quality.

The Broadleaf Silviculture Research and Development (BSilvRD) project, a five-year project funded by the Dept. of Agriculture, Food and the Marine, comprises three main strands which seek to improve the quality of broadleaf plantations:

1. Establishment of broadleaves;
2. Thinning of pole-stage broadleaves – maintaining and enhancing existing good quality;
3. Rehabilitation of poorly performing pole-stage broadleaves.

The rehabilitation strand aims to address the quality issues relating to existing broadleaf plantations through the application of novel treatments and the development of innovative silvicultural solutions (for example, see Short and Hawe 2012 and Short 2013).

Where species/site requirements are not so incompatible, there may be some means to reinvigorate the original species, potentially within environmental conditions which are now more favourable than those existing at the time of original planting. This article introduces stumping and coppicing as a means to rehabilitate poorly performing broadleaves and includes a case-study of a pilot trial that was intended to investigate the rehabilitatory silviculture of a poorly-performing stand of pole-stage sycamore in Ireland. Systematic thinning treatments were conducted and the impressive resultant regrowth from the sycamore stools is now being investigated and managed. Related practices of stumping back and conversion of stored coppice are outlined below.

Stumping back

Stumping back is the practice of cutting back top growth at, or a few years after, planting to stimulate a vigorous initial shoot (Evans 1984). It has previously been known as "heading down" (Nicol 1820, Billington 1825, James 1991), "cutting over" (Bolton 1956) and "cutting back" (Hough 1882). Stumping back is not a new practice and has predominantly been used for broadleaves but is seldom done nowadays. However, its benefits have been known for at least the last two centuries. In his *Memorial on the Culture of Woods* to the French Government in 1742, de Buffon of the Royal Academy of Paris said this about young trees that had been stumped back:

> … they shoot out with vigour the superabundance of their nutriment and produce, the very first year, a shoot more vigorous and higher than the old trunk was after three years. I have repeated this experiment so often, that I can give it as a certain fact and the most useful practice that I know in the culture of woods.

In 1820 Nicol wrote in his Kalendar for the month of March, under the title of "Heading down trees":

> It is now a proper time to examine all plantations which have been three or four years planted, to see if the [hard-wood] trees are in a thriving state; and such as have not begun to grow freely should be headed down to within three or four inches of the ground. The cut must be made with the pruning knife in a sloping direction, with one effort. Great care should be taken not to bend over the tree in the act of cutting. By so bending, the root may be split; a thing which too often happens.
>
> The operation of cutting over young trees should not be performed at an earlier period of the season, because the wounded part might receive much injury from the severe weather in January and February and the expected shoot be thereby prevented from rising so strong and vigorous.

Stumping back is usually done to improve the growth rate or form of young trees, damaged by frost, browsing or other impact, as recorded by the Society for Promoting Christian Knowledge (1851):

> More attention is required by deciduous trees, especially the oak and chestnut, than by the fir tribe, for they seldom grow straight and freely at first. When, therefore, they have stood two years, they should be cut down to the ground, or at least to the last bud or two; this operation should be performed in the autumn and in the following spring one or more strong clean healthy shoots will be sent up. In the ensuing autumn, the best of these should be selected for the future tree and the others removed. The chosen stem will afterwards make rapid progress, as all the strength of the root will be directed to a stem capable of profiting by its supplies, instead of the former hard wooded and stunted plant. Plants so managed will soon surpass in every respect those which are suffered to struggle through their infancy unaided by the pruning knife; not only will a better and straighter young tree be produced, but much time will be gained instead of lost, as might first be apprehended.

More recently Çiçek and Tilki (2007) found that the growth of poorly developing or heavily browsed *Fraxinus angustifolia* (Vahl.) seedlings was increased following stumping two years prior. Mayhead and Boothman (1997) investigated the effect of treeshelter height on the growth of young sessile oak (*Quercus petraea* (Matt.) Liebl.). Sixty percent of the trees in 1.8 m tree shelters bent over and touched the ground after the shelter was removed. It was concluded that the trees would not recover and that the only treatment likely to ensure an upright tree would be stumping back. Billington (1825, p. 70) recommended such a practice with oak suffering similarly:

> When oaks have been drawn up weak and tall, without any side branches, among other trees, which is frequently the case, the best method I believe to be adopted with them, after the others have been taken out, would be to head them down at different heights, when they might be formed with a little art and care into the most beautiful and useful trees; whereas, when they are left in that state, they hardly ever come to anything and are a continual eye-sore.

Köstler (1956, p. 309) recommends stumping back of planted sweet chestnut (*Castanea sativa* Mill.) after severe injury by frost or in the case of ugly growth form. Madden (1945) reports his delight at the result of a stumping back operation carried out in a partially cleared stand of ash (*Fraxinus excelsior* L.) in Ireland in which there were:

> … extensive patches of crooked, deformed and diseased natural ash-neither a straight nor a healthy plant in the lot. There they stood, ten or twelve feet high and, for all their deformity, their cutting back on the morrow afforded me no satisfaction. … After one short year, however, this cutting back of natural ash has proved a definite success. What sturdy, straight shoots! No doubt of where they are going-the sky is the limit. Each stump has sent out from two to six shoots, I take out my rule and measure several, finding that they measure from one foot to eight feet in height. I place the average height at 2 feet 10 inches.

He goes on to suggest that the coppice shoots will be singled the following year, a practice whereby the best shoot is selected and retained whilst the other shoots are removed:

> The secateurs in my hand are itching for the work. Selection from such a pick will be easy and agreeable work.

A nearby planted stand of 7-year-old Norway spruce (*Picea abies* (L.) H. Karst.)/ash mixture in which the ash had similarly been stumped back was not so successful:

> I examine six of the stumps which had been cut back. Three have not

> put out any shoots and the other three have sent out crooked, deformed, diseased and practically horizontal shoots. Where is the sturdiness, the vigour and the health of the natural ash shoots?
>
> He speculated that perhaps the planted ash had smaller root systems and less vigour than the natural regeneration. But an alternative reason could perhaps be the influence of shading from the Norway spruce.

As highlighted by Madden (1945) above, subsequent singling of the coppice shoots should be carried out to favour the best shoot. Bolton (1956) wrote:

> Some hardwoods tend to remain in check for an unduly long time: that is to say, although they remain alive and healthy, they make no height growth. Where this condition is still obtaining by the fourth year it is worth while cutting them over at ground level, when strong, fast-growing coppice shoots will be thrown up. The strongest one of these should be retained, the remainder being removed.

Singling is also highlighted in the British Sylva and Planters' and Foresters' Manual (Society for Promoting Christian Knowledge 1851) cited above.

Stumping back is particularly suited to ash, oak (*Quercus* spp.) and sycamore (van Miegroet 1956, Bolton 1956) but should not be carried out in beech (*Fagus sylvatica* L.) (Bolton 1956, Kerr and Evans 1993) which is not as successful at coppicing. However, young beech are frequently coppiced in mountainous regions of continental Europe (Joyce et al. 1998) when they have been badly damaged during extraction operations and are cut back to produce shoots with better form. Kerr (1995) and Kerr and Boswell (2001) describe the use of stumping back in ash planted in a frosty valley dip, which, despite having been planted densely and with a nurse species, had been frosted back a number of years. The five-year-old ash were stumped back to about 10 cm above ground, stimulating resprouting. The resultant selection and production of one strong shoot with good growth rate led to the shoot tips being above the zone of very cold air after the first season. The effect of stumping back on the growth rate of sycamore is similar. If little sign of growth was seen in sycamore during the second year after planting, Stevenson (1985) had no hesitation in stumping back to ground level and, later, singling to one dominant shoot. Usually the subsequent growth is rapid and the stumped plants soon catch up with the untouched ones (Stevenson 1985). However, this was not the case in common walnut (*Juglans regia* L.) that was stumped back at the time of planting (Hemery and Savill 2001) but it may be that there was insufficient root systems to produce the results other authors have reported from later stumping back operations. Clark and Brocklehurst (2011) stumped back common and black walnuts (*J. regia* and *J. nigra* L., respectively) that exhibited very poor stem form, caused by repeated frosting, 5 or 6 years after planting and had great success. The shoots were subsequently singled resulting in most trees having one single strong shoot with good apical dominance.

Stumping back can also be carried out as a pre-emptive treatment in cases where advance natural regeneration could be damaged by the felling of overstory trees. Joyce et al. (1998) note this for beech and Hiley (1931, p. 74-75) describes its use in oak woodland with advance natural regeneration of ash:

> Ash often regenerates itself freely in old mixed woods, especially under oak which is dying back in the crown and letting in more than the usual amount of light. Where this is happening the oaks may be cut and the advance growth used for stocking the ground, intervening areas being planted up with other trees, including some shade-bearing species. In this way dense groups of ash, which can in time be thinned out to one or two trees may be cheaply secured. The advance growth of ash is likely to be damaged by the removal of the old trees and it is safer to cut it back to an inch or two above the ground before the wood is felled, as it will then sprout very vigorously. This method of cutting back advance growth before felling the big trees over it is regularly applied with success to hardwoods in the Harvard forest in Massachusetts and the same treatment is used with planted out ash on some English estates. It is found that the trees which are cut back sprout so vigorously that they overtake trees which have been left untouched.

As has been demonstrated, stumping back normally occurs when the trees are young. A related practice to stumping back and singling, but carried out in more mature stands, can be employed in the conversion of stored coppice to high forest.

Stored coppice conversion

Neglected stands of coppice develop a high forest structure following growth after the cessation of regular cutting. The resultant trees, known as "stored coppice", may, in comparison to single-stemmed trees, exhibit inferior growth and have worse stem form and butt sweep (Harmer 2004). Often the trees produced are less windfirm. However, the quality of stored coppice can be improved by thinning and singling the stools to leave only the best stem. The French *balivage intensif* system of converting coppice to high forest uses this principle (Troup 1928). Storing coppice is likely to be most successful where stools are vigorous, young and have been cut close to the ground (Harmer 2004). In sycamore an acceptable high forest crop can be formed if shoots are thinned after it has been decided to store coppice (Stern 1989), although Hiley (1931) recommended that, to grow large timber from stored coppice, only rootstocks of six inches or less (approximately 15 cm) should be used because their roots are still vigorous and exposed wounds will soon heal. However, sycamore up to 80-100 years old coppices well (Savill 2013) but the species does not endure many successive cuttings (Troup 1928). It may therefore be more appropriate to convert to sycamore high forest rather than maintain a coppice system. Sycamore coppice regrowth has often been used to restock stands on clearfelled sites (Henriksen and Bryndum 1989, Tillisch 2001).

Billington (1825) has a chapter specific to "reclaiming and bringing woods and plantations that have been neglected, or got into a ruinous stunted state for want of thinning, etc. into a healthy and profitable condition", in which he says:

> …I would begin to head some of them down (the weakest and those with the fewest branches on) to different heights from the ground and perhaps cut some close to the soil, according to circumstances; … Trees of 20, 30, or even more years' growth, might probably be renovated and set in a growing vigorous state again, which would be of immense importance. (p. 303-304)

The B-SilvRD project initiated an unreplicated pilot study in a poorly performing sycamore plantation to investigate the effect of stumping back 17-year-old stems with the objective of producing a productive high forest system. As part of the trial, we are investigating the impact of three systematic thinning intensities and resultant altered light regimes on the consequent sycamore coppice regrowth.

Case study

Site description, trial design and treatments

The 1.2 ha site is situated near the village of Kilkelly, Co. Mayo in the west of Ireland (latitude 53.90°, longitude -8.78°). The site is privately owned and was planted under the Afforestation Programme in 1996 with pure sycamore at 2 m × 2 m spacing (2,500 stems ha^{-1}). Elevation is 125 m and at the time of planting the site was exposed. Soil type is poorly drained acid mineral (EPA 2013).

A consultancy report in March 2009 described the crop as "extremely poor" with relatively extensive areas not having closed canopy and possibly requiring reconstitution via underplanting (Hawe 2009). Top height at this time was 6 m with a projected maximum mean annual volume increment of 4 m^3 ha^{-1} (Yield Class 4) (HMSO 1981). Speculation as to the possible causes for poor performance included: exposure, inappropriate species/provenance choice, mineral soil rooting depth limited to around 30 cm and lack of early maintenance.

Considering the poor performance of the original sycamore crop, discussions between the owner, managers and research staff concluded that systematic line thinning treatments should be carried out with a view to underplant with an alternative species. It was decided to carry out line thinning in three treatments (Figure 1):

1. remove 50% canopy cover by cutting alternate lines (Treatment 1:1);
2. remove 50% canopy cover by cutting 2:2 lines (Treatment 2:2);
3. remove 75% canopy cover by cutting 3:1 lines (Treatment 3:1).

The trial was designed as a pilot demonstration trial rather than a fully replicated research trial. However, the trial has provided indications of areas for further research. Each trial measurement plot consists of one 4-line bay and has at least one similarly treated bay either side of it to act as a buffer between neighbouring treatments.

The thinning was carried out in February 2011, motor manually with low impact quad and timber arch extraction of any viable firewood cords. Underplanting was not carried out directly following thinning as originally planned.

The growing season after the thinning showed strong coppice regrowth from the cut stools; much stronger than had been anticipated and clearly benefitting from improved sheltered conditions than had been the case at the time of initial establishment. The site was now being surrounded by well-established conifer stands on three sides and an overgrown hedgerow on the west side, together with more intimate shelter from the remaining sycamore crop. Observing the strong coppice regrowth, particularly in the 3:1 treatment (see Figure 2), there was an opportunity to examine the potential to reconstitute the sycamore crop, potentially as a two-tier, single species woodland, via singling of the resultant coppice.

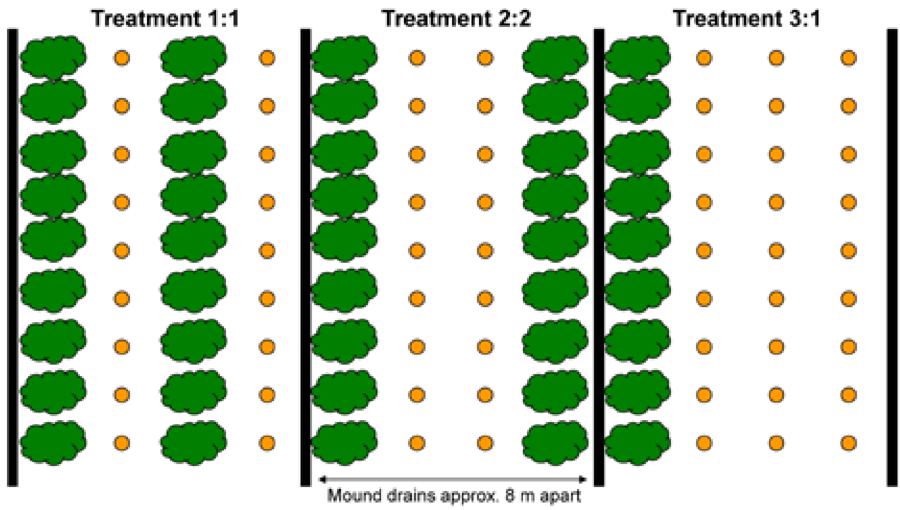

Figure 1: *Diagrammatic representation of the thinning treatments. Circles represent harvested trees. Buffer areas adjacent to each measurement area are not shown.*

Figure 2: *Coppice regrowth in the 3:1 plot at the beginning of growing season 2 following cutting.*

Data collection

After three growing seasons it was visually apparent that there were differences in the coppice regrowth between the three treatments. To quantify this all the coppice stools within each treatment plot were measured in September 2013, at the end of the third growing season since felling. Parameters measured were: height of the tallest two shoots per stool; shoot diameter at 5 cm from the stool of the two tallest shoots; number of shoots per stool; number of shoots >1 m tall per stool. To investigate the light available to the coppice five hemispherical photos were taken per treatment at 1.2 m above ground. Each photo was taken from randomly assigned locations in the mid-line of the treatment. In the 2:2 and 3:1 treatments data from the four coppice stools adjacent to the location were analysed. In the 1:1 treatment data from the two coppice stools adjacent to the location were used. Definitions of the parameters are in the glossary below.

Results

Data are presented in Tables 1 and 2 below and illustrated by Figure 3. The 1:1 treatment plot had less coppice shoots per stool than the 3:1 treatment and a reduced proportion of the shoots were >1 m tall than the 2:2 and 3:1 treatments. Three years after cutting, the height of the tallest two shoots per stool ranged from 40 - 403 cm, the shortest appeared to be in the 1:1 treatment and the tallest appeared to be in the 3:1 treatment. The mean height of the tallest two shoots appeared to be greatest in the 3:1 treatment and the smallest appeared to be in the 1:1 treatment. The mean diameter of the tallest two shoots exhibited a similar trend.

Five hemispherical photos (e.g. see Figure 4) were taken per plot and data from the stools adjacent to them were used to produce means. The two stools adjacent to one photo location in the 1:1 plot were both dead.

Figure 3: *Sycamore coppice understory three growing seasons after maidens were cut to three intensities: a) 1:1; b) 2:2; c) 3:1.*

Table 1: *Data from three plots three years after cutting maidens to three intensities: 1:1; 2:2; 3:1. Numbers in parentheses are standard deviations.*

Parameter	Treatment					
	1:1		2:2		3:1	
No. stools in plot	33		29		59	
No. dead stools in plot	4		5		5	
No. live stools in plot	29		24		54	
% of stools that are alive in plot	88		83		92	
Mean no. shoots per live stool	7.4	(5.34)	8.6	(4.92)	11.5	(6.15)
Mean no. shoots >1m tall per live stool	2.8	(2.57)	6.3	(3.96)	8.6	(5.08)
Mean % shoots >1m tall per live stool	37.0	(32.30)	74.0	(27.10)	75.0	(18.70)
Mean height of tallest 2 shoots per stool (cm)	139.1	(52.63)	194.8	(41.57)	239.1	(60.38)
Mean diameter of tallest 2 shoots per stool (mm)	13.1	(5.62)	20.1	(5.53)	22.4	(5.52)

Figure 4: *Hemispherical photos taken in September 2013, three years after cutting maidens to three intensities: 1:1; 2:2; 3:1.*

There was a positive trend for gap fraction and openness to increase with increased tree lines removed, the greatest being in the 3:1 treatment and the least in the 1:1 treatment (Table 2). The trend for leaf area index (LAI) was negative, with the least LAI in the 3:1 treatment and greatest in the 1:1 treatment. The total PPFD over the canopy was 42.71 mol m^{-2} day^{-1} during the growing season for each of the treatments. The mean total PPFD under the canopy tended to increase with the intensity of tree line removal. The sub-sample of coppice stool data is provided in Table 2.

Table 2: *Data derived from analyses of hemispherical photographs and sub-sampling of coppice stool data three years after intervention. Numbers in parentheses are standard deviations.*

Parameter	**Treatment**					
	1:1		**2:2**		**3:1**	
Gap Fraction (%)	7.00	(0.480)	23.10	(1.960)	38.10	(4.890)
Openness (%)	7.30	(0.490)	24.40	(2.120)	40.30	(5.100)
Leaf Area Index	3.00	(0.200)	1.90	(0.170)	1.30	(0.300)
Diffuse PPFD under canopy (mol m^{-2} d^{-1})	0.63	(0.112)	2.15	(0.251)	3.59	(0.350)
Direct PPFD under canopy (mol m^{-2} d^{-1})	4.07	(0.828)	16.14	(1.851)	24.70	(2.977)
Total PPFD under canopy (mol m^{-2} d^{-1})	4.71	(0.803)	18.29	(1.962)	28.29	(3.296)
Total site factor	0.11	(0.019)	0.43	(0.046)	0.66	(0.077)
Mean % shoots >1 m tall per live stool	37.20	(13.920)	67.00	(21.640)	71.20	(11.940)
Mean height of tallest 2 shoots per stool (cm)	160.10	(37.000)	175.80	(22.530)	224.10	(24.320)
Mean diameter of tallest 2 shoots per stool (mm)	14.80	(2.720)	18.10	(2.540)	21.00	(2.550)

Discussion

The silviculture being applied in this trial is novel in Ireland but a similar systematic thinning regime has been used in Romania for the conversion of hornbeam coppice to high forest. Tulbure and Duduman (2012) describe a trial in which "corridors" or bands 4-7 m wide are created in 15-year-old hornbeam coppice and replanted with a mixture of beech (*Fagus sylvatica*), sessile oak and pedunculate oak (*Q. petraea* and *Q. robur* respectively) with the objective of creating a mixed species high forest system. A more dramatic, but similar, system is described by Marion (1961) for the conversion of coppice systems to high forest with an alternative species in which 3 m wide strips, spaced 5-6 m apart, of poor coppice are bulldozed and replanted with the substitute species. Marion (1961) also notes that strips 1-3 m wide can be used in the substitution of species. Whilst strips 3 m wide are narrow in comparison to those used in our study, Marion was discussing underplanting shade-bearing coniferous species. Evans (1984) provides summarized results of a few rehabilitation treatments employed in a coppice-with-standards system with oak standards over 18-year-old ash and hazel coppice. One of the treatments used was to strip fell leaving 3 m wide "hedges" 16 m apart and replant with oak:Norway spruce 3 row:3 row mixture. The system was found to benefit the form of the oak but yield was reduced compared with clearfelling and replanting with the 3 row:3 row mixture. Our results suggest that, if regeneration is to be from sycamore coppice, 50% or more of the original planted lines of stems need to be felled, but not as alternate lines, resulting in strips 4-6 m wide, to provide sufficient light such that the stools can produce shoots and grow satisfactorily for three years. As the upper canopy continues to close during the following years the coppice growth may become impacted to such an extent that the recommendation should be to fell 75% or more of the original planted lines.

Three growing seasons after cutting, the mean number of coppice shoots per live stool ranged from 7.4 to 11.5 depending on the treatment. Other studies have demonstrated that the number of coppice shoots tends to reduce over time. Stumps from six-year-old sycamore maidens that were coppiced at 15 cm height had produced on average 7.8 shoots per stool after one growing season but this reduced to 3.5 per stool after six growing seasons (Harmer and Howe 2003). Nicolescu et al. (2011) reports 4.6 shoots per stool from 5-year-old sycamore coppice in Romania. With few exceptions, most angiosperm trees with stems <10-15 cm produce numerous coppice shoots after felling and typically 75-90% of these die off within five to ten years. Our results support the idea that the amount of light available to stool shoots also limits their number. The frequency of stool shoots produced relative to the amount of incident light is of no surprise. It has long been known that light plays an important part in the success of stool shoot production. For example, Gayer in 1889 (cited in Brown and Nisbet (1894), vol II, p 179) wrote:

> The first essential for the development of stool-shoots or root-suckers is the supply of light; for stools that are deeply overshadowed, or otherwise deprived of light, either throw out no shoots or stoles, or else develop them only sparsely and indifferently.

Indeed, the coppice-with-standards system requires for its success the careful management of the overstory to ensure that sufficient light is available for the understory coppice stools to thrive (Troup 1928) and continuous cover forestry systems similarly require careful management of light for their success.

Ellenberg's indicator values for British plants (Hill et al. 1999) designates sycamore as an intermediate shade to semi-shade plant when a sapling, more shade tolerant than ash and oak but less so than beech. Niinemets and Valladares (2006) list sycamore as 3.73 ± 0.21 for shade tolerance on a scale of 1 – 5 with 1 being light demanding and 5 being shade tolerant. For comparison, beech was 4.56 ± 0.11, ash was 2.66 ± 0.13 and pedunculate oak was 2.45 ± 0.28. Petriţan et al. (2007) determined quantitatively that sycamore is mid-tolerant of shade. Harmer et al. (2010) use Ellenberg's indicator values to classify sycamore as shade tolerant. Our treatments resulted in 12%, 40% and 62% of the incident photosynthetically active radiation (PAR) being available to the understory sycamore coppice in the 1:1, 2:2 and 3:1 treatments, respectively. The resultant trends in shoot growth broadly agree with that reported by Dreyer et al. (2005) and Delagrange et al. (2006). When PAR was reduced to below 25% of full intensity, sycamore seedling diameter and height growth were greatly reduced (Dreyer et al. 2005, Delagrange et al. 2006) and sapling occurance may be reduced or eliminated when light availability is below a certain threshold (Petriţan et al. 2009).

It should be noted that coppice shoots may differ physiologically from intact stems and can appear more juvenile (Wendling et al. 2014). Leaves of intact plants typically photosynthesise below their capacity. For example, leaves of coppiced red oak (*Q. rubra* L.) saplings in Wisconsin forest openings tended to maintain photosynthetic rates and stomatal conductance near to their morning maxima throughout the day but gas exchange rates of leaves of untreated saplings typically declined during the day following a mid-morning maximum (Kruger and Reich 1993). A similar trend has been reported by Tschaplinski and Blake (1989) for *Populus deltoides* and *P. maximowiczii*×*nigra*. Diurnal photosynthetic patterns of retained stump leaves and new coppice leaves showed that decapitation increased the photosynthetic potential of tissue by increasing net photosynthetic rates in the early afternoon, thereby eliminating the post-midday reduction typical of intact plants.

The height of the tallest shoot per stool of sycamore coppice regrowth in southern England, 2-3 years after cutting, ranged from 0.5 - 4 m with a mean of 1.6 m. Sixty-two percent of the longest shoots per stool were >1.2 m tall (Harmer and Howe 2003).

The difference in the success and growth rate of the coppice shoots between our three treatments is evident (see Figure 3). The range for the tallest two shoots per stool from our study was similar (0.4 – 4.0 m). The mean height of the tallest two shoots per stool from our study ranged from 1.39 – 2.39 m, dependent on the treatment. Approximately 75% of the two tallest shoots per stool were >1 m tall in the 2:2 and 3:1 treatments but only 37% of the shoots from the 1:1 treatment were >1 m tall. The mean height and diameter of the two tallest shoots per stool increased with the amount of available light. Röhrig (1967) observed a similar trend with both height and radial growth. Bonosi (2006) also describes steadily increasing height growth of sycamore seedlings with increasing light availability.

A search of the literature has failed to find any published work on correlating sycamore coppice understory growth parameters to understory light availability or measures of overstory canopy structure (i.e., openness, gap fraction, LAI). Our results suggest a positive trend between the mean diameter of the tallest two shoots per stool and canopy openness, gap fraction, LAI and diffuse, direct and total PAR under canopy. Similar trends were found for the mean height of the tallest two shoots per stool and the percentage of shoots per stool. Some useful comparisons can be made from studies that, by proxy, have affected the overstory canopy structure and the amount of available light to an understory coppice. Gardiner and Helmig (1997) found that the intensity of thinning below of a 28-year-old water oak (*Q. nigra* L.) overstory to either 40% or 60% of original basal area had an effect on coppice shoot height and diameter growth during the first five years. Water oak is a shade intolerant species and by year two, coppice shoots in the heavily thinned plots grew 15% taller than those under the lightly thinned overstory and the difference was maintained five years after the thinning. Shoot diameter increment was similarly affected. Coppice shoot growth reduced as canopy closure advanced. The early benefits of the heavy thinning treatment on stem growth had diminished by year 7 when dominant coppice shoots averaged 2.7 cm DBH and 4.5 m tall, irrespective of the thinning treatment. The heavier thinning prolonged coppice survival and the period between the initial thinning and additional treatments will be determined by the amount of overstory originally removed if coppice regeneration is to be sustained. Lockhart and Chambers (2007) report a similar trial with cherrybark oak (*Q. pagoda* Raf.) and found no significant difference in coppice height during the five years following thinning to either 70-75% or 45-50% original stocking intensity.

The long-term effect of oak standards on growth of a 40-50 year-old hornbeam coppice in a coppice-with-standards system in France was investigated by Bergez et al. (1990) who found no influence of a standard on individual stool growth. However, coppice basal area was negatively affected within 5 m of a standard, despite the shade tolerant nature of hornbeam. It is hoped that our trial will continue to be monitored over the next decade or more so that the full silvicultural impact of carrying out the operations we have conducted can be assessed.

Conclusions

Historical literature provides a wealth of knowledge, much of which is still relevant today. Stumping back could still have a place in Irish broadleaf forestry today. Whilst it must be remembered that the trial is not fully replicated, the results suggest that coppicing/stumping back of pole-stage plantation sycamore may have potential for successful stand rehabilitation if there is enough overstory removed to allow sufficient light for the coppice shoots to progress. Three years after systematic thinning, it appears that the removal of 75% of the tree lines will be most successful, both in producing sufficient shoot growth and sufficient number of shoots to facilitate subsequent singling, but a fully replicated trial across different sites should be initiated to confirm whether this is the case. A pilot trial in the 3:1 treatment has since been initiated to investigate the impact of singling coppice shoots because we believe that the 3:1 treatment will provide the best chance to support the rehabilitation of the stand to a quality high forest with minimal further overstory interventions. Fundamental to the future commercial quality of the re-configured stand is the stem form of the regrowth. This is often excellent, particularly in the 3:1 treatment where shoot extension is greatest. While this may be due to improved growth conditions, it remains to be seen whether this remains the case following singling and on into the rotation but historical literature supports our view. Furthermore, there may be some economic impact by effectively returning a proportion of the stand to year zero. However, this may be offset by more vigorous and better quality material continuing to catch up the original growing stock. A future economic study of the stand rotation may shed some light on this.

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Definitions

Openness	Percentage of open sky (unobstructed by vegetation) in a hemispherical image.
Gap fraction	Fraction of pixels in a hemispherical image unobstructed by foliage.
LAI	Leaf Area Index calculated with the LiCor LAI2000 generalised linear method and corrected for foliar clumping.
PAR	Photosynthetically active radiation, i.e. the 400-700 nm waveband.
PPFD	Photosynthetic Photon Flux Density, i.e. the Photon Flux Density of PAR (also referred to as Quantum Flux Density) is the number of photons in the 400-700 nm waveband measured per unit time on a unit surface.
Diffuse PPFD under canopy	Average Diffuse Photosynthetically-active Flux Density under canopy for the growing season (mol m^{-2} d^{-1}).
Direct PPFD under canopy	Average Direct Photosynthetically-active Flux Density under canopy for the growing season (mol m^{-2} d^{-1}).
Total PPFD under canopy	Average Total Photosynthetically-active Flux Density under canopy for the growing season (mol m^{-2} d^{-1}).
Total site factor	$\frac{\text{Average daily direct+diffuse radiation under canopy}}{\text{Average daily direct+diffuse radiation over canopy}}$

Review of tools for growth forecasting and productivity assessment in forestry in Ireland

Andrew McCullagh[a*] and Maarten Nieuwenhuis[a]

Abstract
A review is undertaken of the forecasting and productivity assessment tools used and approaches adopted in Irish forestry from the latter half of the last century up until today. Descriptions are provided for the methods and the technological or mathematical endeavours utilised alongside the necessities that led to their inception. Forecasting in Ireland has relied heavily on the Forestry Commission yield tables, though a variety of methods have been developed in order to better represent the growing conditions of Irish forests. The challenges of sustainable forest management has led to reappraisals of alternative silvicultural systems, development of which have been hampered by the difficulty in obtaining good quality data.

Keywords: *Forecasting, growth, yield, productivity, model.*

Introduction

Foresters use a variety of tools to efficiently and sustainably utilise the land and maximise yield and profit. Dramatic changes have been witnessed during the previous century – political upheaval that influenced forest policy in Ireland and technological developments which changed the tools used in forest management. The advent of computers and the increased use of mathematics have been beneficial to growth and yield forecasting. Since intensive forest management became the norm, there has been a need for accurate information on forest development. Policy shifts towards sustainable forest management, delivery of ecosystem services and carbon reporting, mean further model improvements and developments are required to improve the accuracy of forecasts and to widen the range of forest parameters included in these forecasts. The range of tools produced and adopted in Ireland for use in forest management planning and decision making are reviewed in this paper, focusing primarily on developments since the middle of the last century.

Forecasting

Efficient forest management requires estimates of stand development and productivity. These forecasts enable the manager to plan operations and arrange timber sales. The Forestry Commission (FC) Yield Tables have proven reliable for forecasting Irish stands since the first table was produced in 1953 (Hummel and Christie 1953). The yield tables are a comprehensive set of tables that allow growth projections from which a management prescription may be adopted. Used mainly for even-aged stands,

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the FC tables are based on the yield class system. Yield class is the maximum mean annual increment of a stand and is utilised to classify stand productivity. Since the volume of a stand of trees is difficult to measure, use is made of Eichhorn's rule, which states that the volume production at a given stand height should be identical for all site types (Skovsgaard and Vanclay 2008). Top height - age curves are then produced and from these a master table is constructed that relates the top height to characteristic stand variables. From this table, the yield models for different yield classes, stocking densities and thinning regimes are derived, forecasts from which are possible while height growth remains vigorous. A comprehensive description of the FC Yield Tables was produced by Joyce (1982), outlining the stages of development from the initial beginnings of yield tables in Europe, to the tables of Edwards and Christie (1981), which are still in use today. These tables were developed using permanent sample plot data. It is accepted that their flexibility is limited since deviation from a prescribed regime reduces forecasting power. Nonetheless, yield tables have been in use throughout Europe since the 1700s, remain in use and are applicable to multitudinous prescriptions in Ireland and the UK. Outside of even-aged stands, the relationships upon which the tables are based no longer hold true (Pretzsch 2009).

The master table mentioned above was revised to account for the metric system and adopted orthogonal polynomial equations to characterise each species' growth (Christie 1972). It has been noted that the tabulation of the equations could be replaced by the use of differential equations for growth projection resulting in the removal of the static element (Broad and Lynch 2006). The PractiSFM decision support system for sustainable forest management has incorporated these equations into its system and uses them to make annual forecasts (Barrett 2009, Barrett et al. 2007).

The yield tables span a range of yield classes that vary for each species. The yield table for thinned and unthinned Sitka spruce (*Picea sitchensis* (Bong.) Carr.) may be applied to stands of YC 6 up to YC 24. However, yield classes in excess of this are not uncommon in Ireland for Sitka spruce (Joyce and OCarroll 2002, McCullagh et al. 2013). Variations in growth and yield between Irish and UK conditions motivated the production of tables developed with Irish data. In 1966, a set of tables based on 101 fully stocked, temporary sample plots for lodgepole pine (*Pinus contorta* Dougl.) was developed, using a regression of the main stand volume on top height, as described in Gallagher et al. (1987). These yield tables highlighted the differences in form between coastal and inland provenances grown in Ireland; the FC tables were based solely on inland provenances. Also highlighted was the observation that higher yield classes were being obtained by the coastal provenance, given similar height and age data (Gallagher et al. 1987). The above issues, along with the adoption of SI units, motivated the production of a revised set of thinned lodgepole pine tables by Phillips and O'Brien (1975).

In Northern Ireland, an unthinned Sitka spruce yield model was produced by Kilpatrick (1978) developing a basal area increment function which was used to produce the yield table. The author highlighted the benefit of non-reliance on a single variable but rather on two (basal area and height), thereby reducing the effect of measurement error. Omiyale and Joyce (1982) produced a yield table for unthinned Sitka spruce. The Bertalanffy-Richards function was used since it is based on the biological concept that the growth of an organism is the net result of the creation and breakdown of cells (von Bertalanffy 1957). Eichhorn's rule was applied and the positive relationship between top height and site productivity was exploited. Volume assortment tables were produced using data from stands of Sitka spruce growing in Irish conditions (Jordan 1992). Using a regression analysis, a master table of volumes and volume assortments was produced for single trees and stands. Results indicate that FC assortment tables were underestimating volumes. These studies have been borne out of the uncertainty of the applicability of the FC Yield Tables to Sitka spruce stands in Ireland.

Increased use of mathematical equations and, later computers, had assisted these developments and by 1995, intensive model development had begun using a new approach to forecasting: dynamic models. This approach allowed greater flexibility since the initial condition or growth history of the stand was not required for forecasts. The system was devised by Garcia (1984) and developed for Irish conditions by Lance Broad and Ted Lynch (2006).

This approach is known as the state-space approach and has been in use in Ireland since 2005. The Irish dynamic models are available in the software program Growfor. Forecasts are possible for stands with varied thinning schedules and those in which the management approach is altered or adjusted. Moreover, the models are relevant to Irish stands as they are based on Irish data and are widely applicable as they adopt stochastic processes to evaluate model parameters. Theoretically-based equations may provide safe extrapolations outside the range of the developmental data; the growth equation upon which Growfor is based, Bertalanffy-Richards, is one such equation (Vanclay 1994). Development on the Growfor system has continued with the addition of models for ash (*Fraxinus excelsior* L.) and Japanese larch (*Larix kaempfaeri* (Lamb.) Carrière) (McCullagh 2013). User-defined assortments have also been added, increasing the flexibility and practicality of the system.

The state space approach models mark a move away from yield class and instead adopt site index: the top height a stand is expected to attain at a base age, 30 years in Ireland. Though used internationally, base ages may vary from country to country depending on rotation. Top height is defined as the mean height of a fixed number of trees per unit area, the number of trees and the unit area adopted is also country specific, in Ireland it is 100 trees per hectare. The use of yield class in the yield tables assumes that thinnings are conducted on a schedule, whereas the state space model based on site index makes forecasts from any point during the rotation of a stand independently of the management or thinning schedules. Site productivity enters the dynamic model via the top height equation, the end result being a modification of the time scale. Also adopted were plot specific parameters which result in polymorphic curves. The alternative, being the less flexible anamorphic or guide curves which use global parameters across plots, can also be used, but previous studies indicate polymorphic curves provide a better fit for Irish conditions (Broad and Lynch 2006).

Research was conducted into another nonlinear methodology for growth and yield forecasting in which parameters were estimated using partial differential equations (Fekedulegn 1996). Partial derivatives are expected to produce more efficient and precise results. The study analysed the partial derivatives of biologically realistic functions which are known to produce sigmoid curves. Sigmoid curves are used to describe the general pattern of forest growth: accelerated growth in adolescence, declining with age after what is termed an inflection point in the curve. This study found the Gompertz and logistic functions to be most efficient when quantifying stand growth parameters.

A top height model was produced for Sitka spruce using nonlinear quantile regression (Lekwadi et al. 2012). Quantiles were used as surrogates to classify the spruce data into polymorphic site classes and. The Chapman-Richards growth function was fitted to the quantiles using nonlinear regression. The nonlinear quantile regression approach was compared to anamorphic curves and proved better and more robust than them.

The models described so far are stand level models which implies input and output variables and forecasts are made at the stand level. In 2007, development of the single tree model Carbware began, in which data is processed at the individual tree level. One of the main benefits of this approach is its applicability to stands in which age is indeterminate, i.e., uneven-aged or mixed stands. As each tree is to be measured, data costs are higher and computing time can be significantly greater than that of stand model approaches. Systems of equations model the behaviour of the tree in relation to the environmental conditions and stand dynamics during a growth period are evaluated tree by tree (Pretzsch 2009). Stand level variables are obtained by aggregating the individual tree measurements. Porté and Bartelink (2002) concluded that these are the best models for mixed species stands, while Peng (2000) claimed they are best for uneven-aged stands. These models allow for great flexibility in relation to species combinations and stand structures, management regimes and regeneration methods (Pretzsch 2009). Competition is modelled through competition indices which are classified by the utility or not of a tree's spatial coordinates. A single tree model is distance dependent if the locations of the subject tree and its neighbours are utilised. Single tree growth models have been in development for at least five decades (Liu and Ashton 1995). The area of influence is a widely used competition index; defined as a circular horizontal projection around a tree in which the tree competes for resources. Should the area of influence of one tree overlap with that of another tree, it is assumed that the trees are in competition, the amount of which depends on the area of overlap. Ek and Monserud (1974) developed an individual tree, distance dependent growth simulator called FOREST. As well as using the approach above, the authors used the potential modifier approach in which the maximum growth of a tree is assumed to be reducible by competition. An open grown tree is an example of a tree that is assumed to be growing to its maximum potential.

Carbware is a single tree growth model that simulates carbon dynamics in the forest and between forests and the atmosphere, developed by Black et al. (2012). Carbware is a distance independent model and competition indices used include the basal area of trees larger than the subject tree, the crown ratio and the crown competition factor. It is based on National Forest Inventory data (NFI 2007) and is used in carbon reporting under the terms of the Kyoto Protocol. It simulates the diameter increment of individual trees for species cohorts and is capable of making forecasts for single species even-aged stands, as well as mixed and uneven-aged stands by aggregating data for single trees.

Site productivity

Traditionally site classification had been focused on matching the most appropriate tree species to a site. Cajander (1926) devised vegetation site types in which climax vegetation is classified into habitat or site types. In Ireland, there has been considerable research conducted on the topic of site classification since correct matching of the species to the site is intended to ensure the landowner obtains the highest possible level of productivity. O'Carroll (1993) examined the yield prediction of conifers on peat, identifying physical site factors that influence production. Farrelly (2009) examined the expanded role played by site classification in recent years, specifically, multifactor classifications and the wider concerns related to sustainable forest management, carbon sequestration and environmental issues (Farrelly et al. 2011a, Farrelly et al. 2011b, Farrelly et al. 2011c).

The decision support system Climadapt is a web based application that can differentiate the effect of climate variables, allowing future projections of climate change scenarios under which analysis of species suitability to site may be undertaken (Ray et al. 2009). Climadapt is based on the multifactor system from the UK, the Ecological Site Classification developed by Ray (2001), which is a knowledge-based system that combines observations, experimental results and professional expertise of FC scientists. The system was scaled and calibrated for Irish conditions under the CLIMADAPT project.

Current challenges

Model performance is evaluated by the accuracy and precision of its forecasts (Soares et al. 1995). Hence, good quality data are a prerequisite to model development. The NFI is an important data source, recording changes in the national forest estate between the years 2006 and 2012. It is expected that successive rounds of measurements will take place, on a five year cycle, into the future and add to this resource. Use of the NFI for growth modelling purposes is challenging due to its concentric sampling design. Trees are measured and counted based on different minimum diameter thresholds in each circle. Ingrowth is the term used to describe trees that are not recorded in the first cycle but are recorded in the second cycle as their diameter has then reached the minimum diameter threshold for that circle. These trees confound growth increment values required in growth modelling. Another issue is that measurements for top height are not taken in the NFI. Methods to estimate top height are available, but their performance has not yet been evaluated.

The Natforex database (www.natforex.ie) is an alternative data source which comprises 140 historic experiments and trials dating back to 1957. This data source has the potential to be used for model development, analysis and validation. A limitation of these data is that for uneven-aged or mixed species models, coordinates of the measured trees and crown measures are often required for completion indices and these were not typically collected as part of these experiments.

Current research

Current modelling endeavours include research into determining if the dynamic modelling approach Growfor can be used for mixed species stands. One approach being investigated is a doubling up of the three variable single species method, using three variables per species for a two species stand. The argument is that one may use as many variables as necessary to fully represent the state of the system, though this creates a further challenge in that one may potentially have too many parameters and not enough data with which to undertake parameter estimation. Competition is not defined in the state space approach, though its effect will be contained in the growth trajectories of the two species and, therefore, its simulation is deemed unnecessary.

The use of NFI data to evaluate the Carbware and Growfor models and identify any potential refinements is also being investigated. The NFI can provide an indication of the performance of both models against the national forest estate. Carbware was developed using Coillte permanent sample plot (PSP) data while Growfor used a combination of PSP and temporary sample plot data. For Carbware, site factors are to be included in the diameter increment function and the stem profile models recently developed in the Treemodel project will be used to evaluate the assortment functions. This research will also give an indication of model suitability for the forecast of tree and stand development under alternative silvicultural systems.

Conclusions

Industry has adopted the current models as they have met their objectives. However, their applicability to mixtures and alternative silvicultural systems remains to be determined. The Irish dynamic models were born out of necessity and the need for relevance and accuracy in relation to timber production. Site classification now encompasses the wider environment, as opposed to just matching the species to the site and, similarly, alternative modelling systems will be produced when they are most required by users or when policy changes. Until then, the current approach of adapting existing models is appropriate. Moreover, alternative modelling systems require good quality data, comprising requisite variables in consecutive measurement cycles and the establishment and maintenance of new experiments to collect such data (e.g. the establishment and measurement of permanent sample plots to provide data to construct and or calibrate empirical or process-based models) require a constant supply of funds.

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Two further threats to Ireland's trees from non-native invasive Phytophthoras

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Abstract
The genus *Phytophthora* contains many plant pathogens, including the causal agents of sudden larch death (*Phytophthora ramorum*) and of the late potato blight (*P. infestans*). *Phytophthora* species are estimated to be one of the most threatening biotic agents to forest health worldwide. The species *P. austrocedri* and *P. pinifolia* are currently causing disease epidemics in forests in Argentina and Chile, respectively. Although neither species has yet been recorded in Ireland, *P. austrocedri* has recently been found in Britain. The threat that *P. austrocedri* and *P. pinifolia* pose to Irish forests is briefly reviewed in this paper. The threat level posed by these species is ranked in relation to the risk of (i) entry into Ireland and (ii) likely establishment of species in the wild in Ireland. *P. austrocedri* is of medium threat to Irish forests, given that it is currently present in Britain and has been found in 2001 in Germany on an imported ornamental juniper plant. Furthermore, known hosts of *P. austrocedri* are distributed across the Irish landscape. *P. pinifolia* was ranked as being a low level threat to Ireland's forests. This ranking is a result of the lack of any obvious entry pathway for the pathogen into Ireland and the low frequency of suitable hosts for the organism in Ireland. A large degree of uncertainty in the biology of these organisms was evident from this analysis. Once a pathogen becomes established in the wild, it can be very difficult to eradicate. Being situated at the edge of Europe, Ireland is in a good position to monitor current forest epidemics in mainland European forests and to act to prevent similar outbreaks in Irish forests.

Keywords: *Forest pathogen, invasive species, pest risk analysis, South America, juniper, pine.*

Introduction
Phytophthora species are a significant threat to forest health worldwide (Balci and Bienapfl 2013, Jung et al. 2013a). More than half of the currently described 120 species are found in forests and many of these are pathogenic on trees and woody shrubs (Scott et al. 2013). In Ireland and Britain several *Phytophthora* species have been found causing damage to trees and shrubs in natural environments. These include *Phytophthora alni* (Brasier and Kirk), *P. kernoviae* (Brasier, Beales and Kirk), *P. lateralis* (Tucker and Milbrath), *P. ramorum* (Werres, De Cock and Man in't Veld) and *P. pseudosyringae* (Jung and Delatour) (Brennan et al. 2010, Jung et al. 2013a, McCracken 2013, Denton 2014). All of these species are non-native and were most likely introduced on living plants. In South America, two of the most serious forest

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pathogen epidemics at present are Mal del ciprés (cypress sickness) in Argentina and Daño foliar del Pino (pine foliar damage) in Chile (Frankel and Hansen 2011), caused by *P. austrocedri*[1] (Gresl. and E.M. Hansen) and *P. pinifolia* (Alv. Durán, Gryzenh. and M.J. Wingf.), respectively. Both of these *Phytophthora* species are assumed to be non-native to these countries and were likely introduced by humans. Neither of these species has yet been recorded in Ireland, but *P. austrocedri* has recently been found in Britain (Green et al. 2014). These two species can be added to the list provided by McCracken (2013) that identified pathogens and pests with a reasonable chance of threatening the health of Irish trees.

The aims of this article are to review the current literature on both of these pathogens and assess the level of threat they pose to Irish trees and forests, taking into account the likelihood of entry and establishment of the organisms in Ireland. The official process of rating the phytosanitary threat that a non-native organism poses to the plant health of a country is known as Pest Risk Analysis (PRA). While this article is not an attempt to carry out a PRA for *P. austrocedri* or *P. pinifolia*, these pathogens were assessed under one of the main sections of the PRA process, namely "probability of introduction and spread" (ISPM 2) from an Irish context. A further aim of this article is to bring these emerging forest pathogens to the attention of Irish foresters, similar to the warning given by Keane (1986) of the future threat (now realised!) of *P. lateralis* to Lawson cypress (*Chamaecyparis lawsoniana* (A. Murray) in Ireland.

The emergence of P. austrocedri *in Argentina and Britain*

The disease symptoms of Mal del ciprés were first noted as far back as 1950 in trees within the Isla Victoria forest experiment in the Patagonian region of Argentina (Greslebin et al. 2005). As often happens with *Phytophthora* epidemics on trees, the forest decline was first attributed to several other factors (both biotic and abiotic) before the causal agent was identified. Finally, in 2007 collaborative work between Oregon State University and Argentinian researchers led to the discovery and naming of the causal agent, *P. austrocedri* (Greslebin et al. 2007, Greslebin and Hansen 2010). The disease now extends at least 400 km south from the Neuquen province through the Rio Negro and Chubut provinces of Argentina (Velez et al. 2014). The current disease epidemic is thought to affect only the endemic tree species, Chilean cedar (*Austrocedrus chilensis* D. Don) in the forests of the Patagonian region (Greslebin et al. 2007) and causes high mortality leading to predicted changes in the future composition of these forests (Amoroso et al. 2012). Recently however, a pest alert

[1] Although the use of the synonym *Phytophthora austrocedrae* has been frequent in the literature and online, at the 7th Meeting of the International Union of Forest Research Organisations Working Party (IUFRO) 7.02.09, entitled Phytophthoras in Forests and Natural Ecosystems, a decision was made to adhere to the original and correct version of the species name, *Phytophthora austrocedri*.

identifying the threat of *Phytophthora austrocedri* to the heathland species common juniper (*Juniperus communis* L.) and also to Lawson cypress and Alaska yellow cedar (*Cupressus nootkatensis* D. Don) was circulated by the Forestry Commission (2014a). In Britain, symptoms of disease were noted on native common juniper at several sites in northern England and Scotland in the mid 2000's (Green et al. 2014). The relatively rapid dieback of juniper has since been noted in many areas in Scotland and England, with *P. austrocedri* being identified as the causal agent. *P. austrocedri* is now known to be widely distributed on common juniper across northern Britain, with two distribution clusters of the pathogen; in the lake district of Cumbria and in the northeast highlands of Scotland where common juniper is most common. To date, *P. austrocedri* has not been reported in any natural stands south of Yorkshire. The organism has also been found in private gardens in England and Wales (Forestry Commission 2014b). All of the findings in Britain, except two on individual Lawson cypress and Alaska yellow cedar trees, have been on juniper. All of the known hosts of *P. austrocedri* so far have been from the Cupressaceae, possibly indicating that the organism has an affinity to this plant family (Green et al. 2014). Although it is not clear whether the pathogen is native or introduced to either Britain (Green et al. 2014) or Argentina (LaManna et al. 2012, Velez et al. 2014), the genetic evidence seems to point to it being an introduced species in both regions.

Studies using *P. austrocedri* isolates from Argentina have found that the species has non-deciduous sporangia (i.e. infective spores that do not fall off easily) and infection by *P. austrocedri* occurs via the root as the motile zoospores (i.e. swimming spores released from sporangia) swim through water in the soil to infect the roots. Progression of the infection up the inner bark and sapwood follows, causing necrosis of the phloem and xylem which leads to disrupted carbohydrate and water transport, resulting in the plant being girdled (Velez et al. 2012). Early symptoms include thinning of the crown foliage (Figure 1) and bleeding lesions on the lower stem. As with other soil borne pathogens, tree death at the landscape scale can radiate out from central infection foci (Figure 2). Studies in Britain are underway to describe the ecology of the organism and the infection process on juniper (Sarah Green personal communication). *P. austrocedri* is spread at a local level in watercourses and by animal and humans moving soil in Argentina (La Manna et al. 2012, Hansen 2015). A similar local mode of spread is being postulated by researchers in Britain, with scientists investigating the role of animals in spreading the disease (Sarah Green, pers. comm.). Furthermore, phytosanitary precautions, such as washing debris from footwear, are being encouraged for people that visit affected areas. The role of plant nurseries in spreading the organism over long distances through international trading of infected juniper plants has also been suggested (Forestry Commission 2014a, Werres et al. 2014).

Figure 1: *Declining and healthy* Austrocedrus chilensis *trees in Isla Victoria, Argentina. Tree decline can be seen as a thinning of foliage in the trees to the left centre and centre of the picture. The tree on the right centre of the picture appears to be unaffected.*

Figure 2: *Tree death as a result of Mal del cipres in Patagonia, Argentina. The light green trees are healthy* Austrocedrus chilensis*, the dark green trees are* Nothofagus *spp., the grey areas are dead* A. chilensis *trees*.

Occurrence of *Phytophthora pinifolia* in Chile

Forest damage caused by *P. pinifolia* was first recorded in Monterey pine (*Pinus radiata* D. Don) forests in coastal Chile in 2004 (Ahumada et al. 2013a). It is generally accepted to be the most serious threat to pine forestry in Chile because of its rapid spread and its ability to damage pine trees of all ages. The organism mainly affects the foliage and non-fatal infections are the norm with many areas of previously infected forest showing recovery. The area of pine forests affected by this disease has fluctuated from year to year, increasing from an initial 70 ha in 2004 to the maximum recorded 60,000 ha in 2006. From 2007 onwards the area affected varied considerably, with the area affected in 2011 totalling 2,000 ha (Ahumada et al. 2013a). In recent years the epidemic seems to have collapsed, with symptoms only being seen on scattered pine trees (Hansen 2015). Given the absence of any disease symptoms prior to 2004 and the low genetic variation in the disease population in Chile, it is believed that the pathogen is an introduced species (Durán et al. 2010), probably becoming established in Chile in the years just prior to 2004.

Infection by *P. pinifolia* typically occurs during the wet seasons (winter and spring in Chile), with the pathogen infecting the needles and succulent tissue of the tree via sporangial spread in rain splash and rain mists (Ahumada et al. 2013a). Infection often causes black bands on the needles, with the infected needles dying relatively quickly. These black bands on the needles are the sites of sporangia production (Durán et al. 2008). The foliage at the top of infected trees turns grey, with the foliage of the entire tree turning brown at the end of spring (Ahumada et al. 2013a). The pathogen rarely enters the bark or wood of the host and would appear to persist mainly in the needles (Ahumada et al. 2012). The next season's needle growth is not affected, unless reinfection from litter or near-by infected trees occurs. However, several consecutive years of infection can lead to high stress on the trees, making them susceptible to secondary infections from other pathogens/facultative pathogens which can cause tree death. The incidence of death declines as tree get older, with the pathogen typically killing 1-2 year-old saplings, yet rarely killing trees older than 6 years-old.

Suitability of climate and host range for P. austrocedri *and* P. pinifolia

The cool temperate maritime climate of Ireland provides conditions favourable for the establishment and survival of many *Phytophthora* species, most of which have a wide threshold of growth temperatures, ranging from 1 °C to 35 °C (Erwin and Riberio 2005). Being a semi-aquatic organism, *Phytophthora* also favours moist conditions and the presence of free water is necessary for natural infection via zoospores (Erwin and Riberio 2005). Future climate change predictions for Ireland indicate that temperatures will likely rise c. 1.5 °C while rainfall during the autumn/winter will also increase as this century progresses (Mc Grath et al. 2005). These changes will increase the suitability of the Irish climate for *Phytophthora* establishment, directly by allowing better conditions for infection and growth into the plant and indirectly by stressing the plant with knock-on negative effects on plant defences (Pautasso et al. 2012).

The threat assessment for *P. austrocedri* carried out by British scientists indicated, at that time, that the natural environment of Britain was suitable for establishment of the organism (Webber et al. 2012). Studies using two Argentinian isolates of *P. austrocedri* revealed that the organism can grow at temperatures ranging from 10 to 25 °C, with an optimum of 17.5 °C (Greslebin et al. 2007). Further work carried out on a wider range of isolates (from Britain and Argentina) has found that 25 °C is the maximum temperature for growth (Sarah Green pers. comm.). This range of temperatures is within the normal range for Ireland and Britain. The range of temperatures for growth of *P. pinifolia* is from 10 to 30 °C, with optimum growth achieved at 25 °C (Durán et al. 2008). This range also occurs within Ireland's temperature range. The climatic range for *P. pinifolia* is said to be very similar, although slightly cooler, than that of *P. ramorum* in North America (EPPO 2010). Given that the climate of Ireland and Britain are suited to *P. ramorum* establishment, it could be expected that *P. pinifolia* would also survive under Irish climatic conditions. Indeed, a climate modelling task commissioned by EPPO (2010) identified the south west of Ireland to be climatically suitable for the establishment of *P. pinifoli*. The Atlantic coast region of Ireland may also be more conducive to the spread of the pathogens if they did invade. The rainfall in the west and in mountainous areas ranges from 1,000 mm to more than 2,000 mm in some areas (MET Eireann 2015). Free water is necessary for infection by many *Phytophthora* species and the infection levels and spread of *P. austrocedri* and *P. pinifolia* would also increase under these conditions.

At present, neither *P. austrocedri* nor *P. pinifolia* have been reported in Ireland. *P. austrocedri* has been recorded in Britain and the finding of a specific plant pathogen in Britain is often indicative that the same pathogen may soon be recorded in Ireland (Table 1). This is partly because both countries trade in the same European market, in similar commodities from those markets and have a similar range of habitats (both artificial and natural). When taking the ecology of the two pathogens into account, the Irish climate appears suitable for their establishment in the wild. Given that *P. austrocedri* can survive in the wild in Britain, probably indicates that it would also be able to survive in Irish conditions. Furthermore, given that similar habitat to that infected by *P. austrocedri* also exists in Ireland, the likelihood of establishment in Irish juniper ecosystems should be taken as high. The temperature in Ireland is often below the minimum temperature for growth of *P. pinifolia* (10 °C), however, other species with similar minimum growth temperatures (e.g. *P. cinnamomi*, *P. richardiae*) have been found infrequently in the wild in Ireland in the past (Muskett and Malone 1974). This indicates that the Irish climate, which is considered unfavourable for the disease, cannot be taken as a guarantee that a species will not survive in the wild. In periods of unfavourable conditions, many *Phytophthora* species form resistant "resting" structures. *P. pinifolia* does not produce any known resistant structures, but *P. austrocedri* can produce them in the form of oospores (Greslebin et al. 2007). These structures would enable the species to survive at conditions outside of its normal growth range, for example at low temperatures or under low water availability, as has been shown for *P. cinnamomi* in Australia (Jung et al. 2013b).

The host range of both *P. austrocedri* and *P. pinifolia* has so far been shown to be rather narrow - with just four (*A. chilensis*, *J. communis*, *C. lawsoniana*, *C. nootkatensis*) and one (*Pinus radiata*) known hosts in the wild, respectively. Common juniper has the largest worldwide natural distribution of any woody plant, extending across the northern hemisphere from Asia through Europe and North America (Eckenwalder 2009). In Ireland, common juniper occurs in montane and heath ecosystems, especially along the north and west coast (Cooper et al. 2012). Of the known tree hosts to occur in Ireland, both *C. lawsoniana* and *C. nootkatensis* have a rather restricted distribution, especially the latter. *C. lawsoniana* is commonly used as an amenity species and infrequently (<360 ha; NFI 2012) as a forestry species. If *P. austrocedri* is indeed restricted to hosts within the plant family Cupressaceae, then the species coast redwood (*Sequoia sempervirens* (D. Don) Endl.) and western red cedar (*Thuja plicata* Donn ex D. Don) which make up 70 ha of Irish forests could also be susceptible.

Of similar restricted distribution in Irish forestry is Monterey or radiata pine (*Pinus radiata*), the only known host for *P. pinifolia* in the wild, which only accounts for 240 ha of Irish forests. Planting guidance for the use of *P. radiata* recommends planting in warm regions, such as the south and south west of Ireland (Horgan et al. 2004). This also happens to be the area of Ireland most suitable for epidemics of other forest *Phytophthora* species, *P. ramorum* and *P. kernoviae* (DAFM 2014a), which might indicate suitability of the climate in this region for *P. pinifolia* also.

Table 1: *First record of selected plant pathogens in Britain and Ireland. Data from EPPO reporting service (http://archives.eppo.int/EPPOReporting/Reporting_Archives.htm).*

Outbreak	Britain	Ireland
Phytophthora ramorum in horticulture	2002	2002
P. ramorum in Rhododendron outdoors	2003	2004
P. ramorum in Japanese larch outdoors	2009	2010
P. kernoviae in Rhododendron outdoors	2003	2008
P. lateralis in Lawson cypress outdoors	2010	2011
Hymenoscyphus fraxineus (syn. *Chalara fraxinea*) in horticulture	2012	2012
H. fraxineus (syn. *C. fraxinea*) in ash outdoors	2012	2013

In Irish forestry, four pine species (*Pinus contorta* (Doug.), *P. sylvestris* (L.), *P. nigra* (J.F.Arnold), *P. radiata*) make up about 70,000 ha of the forest estate (NFI 2012). Only *P. radiata* was tested for susceptibility to *Phytophthora pinifolia* in the laboratory tests of Ahumada et al. (2013b) and these tests indicate that *Pinus radiata* was one of the most susceptible. There was a large variability in susceptibility between the nine *Pinus* species tested. This variability in susceptibility was further reflected in the evidence from field observations, which showed that other conifers, including *P. pinaster* (Ait.), remained uninfected despite being in the vicinity of infected *P. radiata* trees. This field monitoring evidence also indicates that *Phytophthora pinifolia* is restricted to hosts of the genus *Pinus* in the wild.

Introduction pathways for P. austrocedri *and* P. pinifolia *into Ireland*
In phytosanitary terms, a pathway is a route by which a pathogen or pest can move from one region to another. The two main pathways known to be important in spreading plant pests and pathogens internationally are the "wood packaging material" (ISPM 15; see also Humble 2010) and the "plants-for-planting" (ISPM 36, see also EPPO 2012) pathways. Plants-for-planting are officially defined as "Plants intended to remain planted, to be planted or replanted" (ISPM 5). The plants-for-planting pathway has been highlighted as a major contributor to the worldwide spread of plant pathogens (Webber 2010), including the internationally important pathogens *P. cinnamomi* Rands (cinnamomi root rot), *Cronartium ribicola* J.C. Fisch. (white pine blister rust), *Mycosphaerella pini* Rostr. ex Munk (Dothistroma needle blight) and *P. ramorum* (sudden oak death, sudden larch death). Trade in juniper plants has been implicated in the introduction and spread of *P. austrocedri* in Britain (Green et al. 2014). Indeed, analysis of archived *Phytophthora* specimens isolated from imported plants in Germany in 2001 indicated that the pathogen was found previously on a *Juniperus horizontalis* Moench sample (Werres et al. 2014). The phytosanitary threat assessment for *P. austrocedri* also highlighted the role of the plants-for-planting route in disease spread and warnings were given about the lack of any specific phytosanitary requirements for *P. austrocedri* in the EC Plant Health Directive, making further introductions of the pathogen from Europe into Britain likely (Webber et al. 2012). From 2010 to 2014, the value of imports of live outdoor plants into Ireland totalled €1.5 million (EUROSTAT 2015) and this category includes to a small extent juniper planting stock. Regarding *P. pinifolia*, the main pathway of introduction is also through plants-for-planting, most likely of *Pinus* species. Importing of *Pinus* trees, as well as other conifers such as *Abies*, *Pseudotsuga* and *Juniperus* spp. is prohibited into the EU from a third country under the EU Plant Health Directive (2000/29/EC). Given the already existing dangers these plants could pose because of the occurrence of other *Pinus* pests (e.g. pine wilt nematode) and diseases (e.g. *Dothistroma* needle

blight, pine pitch canker) in other regions, it is unlikely that *P. pinifolia* will enter Ireland via this pathway. Ireland has in the past imported living forest trees from EU countries; however, there have been no recorded imports of this commodity since 2009 according to available data (EUROSTAT 2015).

Are P. austrocedri *and* P. pinifolia *imminent threats to Ireland's trees?*

By reviewing the available literature on both *P. austrocedri* and *P. pinifolia* and taking into account the climate and suitable host distribution in Ireland, it is possible to rate in a similar system to that of McCracken (2013), the level of danger that these organisms will pose to the health of trees and forests in Ireland (Table 2). Given the likely pathway for entry and the widespread distribution of possible hosts for *P. austrocedri*, this species should be rated as of medium concern to Ireland's trees, similar to the ratings for *P. kernoviae* and *Pseudomonas syringae pv. aesculi* (horse chestnut bleeding canker) (McCracken 2013). While the risk of entry is high, the number and distribution of tree hosts at risk from the organism is only moderate, thus lowering the threat level of this organism. Outside of Irish forests, the risk to Irish ecosystems containing common juniper from *P. austrocedri* is very high. Juniper distribution in Ireland is declining due to a number of factors, including encroachment and livestock grazing (Cooper et al. 2012). In Britain the spread of *P. austrocedri* has been attributed to several possible causes, including where juniper habitats were re-established with nursery-grown juniper plants, the high number of visitors to juniper sites by nature conservancy groups (e.g. Royal Society for the Protection of Birds; RSPB) and grazing by livestock on juniper sites. Given that nursery-grown plants were used in Britain for juniper re-establishment and that nursery-grown plants have been found to be infected with *P. austrocedri*, it is possible that such re-establishment works inadvertently spread the disease. In Ireland, care must be taken not to introduce and spread *P. austrocedri* into Irish juniper habitats.

Phytophthora pinifolia on the other hand, is unlikely to enter the country and

Table 2: *Diseases caused by* Phytophthora austrocedri *and* P. pinifolia *of concern to Irish trees and forests.*

Causal agent	***Phytophthora austrocedri***	***Phytophthora pinifolia***
Disease name	Mal del ciprés	Daño foliar del Pino
Main host of concern	Common juniper and other members of the family Cupressaceae	Monterey pine and other *Pinus* species
EPPO status	No EPPO status; Rapid Risk Assessment (Webber et al. 2012)	Alert list 2009-2013; Rapid PRA planned
First report in Ireland	Not reported	Not reported
Level of concern	Medium	Low

if it did enter it is unlikely to find a suitable host. For these reasons it should be rated as an organism of low threat to Irish forestry (Table 2), similar to *P. lateralis* and horse chestnut leaf miner *(Cameraria ohridella)* (McCracken 2013). Probably of more threat to the pine forests of Ireland are the fungal pathogens *Mycosphaerella pini* (causal agent of *Dothistroma* needle blight) and *Gibberella circinata* (Nirenberg and O'Donnell) (causal agent of pitch pine canker) should they ever enter the country.

It must be remembered though, that this analysis is rudimentary in many ways and thus underestimates the actual threat level of these pathogens. As with other analyses of the phytosanitary threat of pathogens and pest (e.g. PRA), uncertainty is an issue (Burgman et al. 2014). There are currently many areas of uncertainty regarding the threat posed by these two *Phytophthora* species, such as lack of information about the biology of the pathogens, their host range and the introduction pathways they could use. Future research into where these pathogens come from, how they interact with their host and the environment and possible ways to prevent/mitigate their respective epidemics, may remove many of these uncertainties.

Conclusions

The threat level to Irish trees from the pathogens *P. austrocedri* and *P. pinifolia* were rated as medium and low, respectively. Other pathogens absent from Ireland yet present in Britain, Europe or world-wide probably pose more of a threat to Irish forestry. In particular, pathogens and pests that threaten the health of Ireland's spruce forests, especially Sitka spruce, are more worrying and need to be identified via horizon scanning exercises. Forest pathologists have realised that the best and often only effective strategy for forest pathogen management is exclusion (Roy et al. 2014, Hansen 2015). With this in mind, research focus has moved from a reactive to a more proactive emphasis. Horizon scanning (Eschen et al. 2014), spread modelling (Pautasso 2013), trait analysis (Philibert et al. 2011) and sentinel planting (Vettraino et al. 2015) research are some of the ways in which forest pathologists and entomologists are forecasting what could be the next Dutch elm disease or ash dieback epidemic. The switch to a more proactive focus is also occurring at policy level in Ireland, with the recent forest policy report containing a strategic action to monitor emerging pests and pathogens of forest trees abroad to prevent introduction into Ireland (DAFM 2014b). Ireland is often one of the last countries to get a forest pathogen or pest that is spreading through Europe (e.g. ash dieback) and this is partly due to being an island on the edge of Europe. This position offers us the advantage of anticipating and being prepared for the most likely threats by monitoring pathogen and pest developments (and movements) in Europe. Hopefully this will allow us to make timely changes that prevent or mitigate against future epidemics in our forests.

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Payments and markets for forest ecosystem services in the USA: lessons for Ireland

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Abstract
The importance of ecosystem services (ES) to social and economic activity has long been recognised but these services, which are often recognised as public goods, are rarely accounted for directly in commercial forest management outside of meeting regulatory requirements. The Millennium Ecosystem Assessment (MEA) brought the importance of ES into focus and identified that the majority of services have been deteriorating in recent decades, which calls into question the effectiveness of existing conservation efforts. Payments for ecosystem services (PES) create financial incentives for landowners and natural resource managers to protect or enhance the goods and services that their forests produce. Such market-based mechanisms for conservation are recognised in international and EU policies as having significant benefits. A number of payments and markets for ES have been established in the USA for some time and include publicly funded schemes and voluntary and regulatory markets. Regulatory markets have been established to mitigate damage to water quality, wetlands and habitats of listed species guided by federal legislation. Voluntary markets for carbon have been successful in allowing private, non-industrial forest landowners to enter carbon markets on a limited basis. This review describes the development of the main PES schemes in the USA and provides a number of examples of their application. In addition the potential benefits, drivers and challenges of implementing PES are described, with regard to the perspective of smaller forest owners in Ireland.

Keywords: *Payments for ecosystem services, water markets, wetland mitigation banking, carbon trading*.

Introduction
Ecosystem services (ES[1]) are commonly defined as the "benefits people obtain from ecosystems" (MEA 2005). They range from basic materials that come from the environment, such as timber, to complex processes related to nutrient cycling and soil formation that underpin the functioning of whole ecosystems. Although these benefits have long been recognised and studied, according to the Millennium Ecosystem Assessment (MEA) many of them are under threat, degraded or declining. As these services underpin economic activity and human welfare more generally, the impact of their decline extends far beyond the ecosystems from which they stem. Paying landowners to conserve or produce ecosystem services has been identified as one

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[1] A list of abbreviations used in this paper is included as an appendix.

of most promising approaches to addressing their continuing decline (MEA 2005). Essentially such payments address the failure of traditional markets to account for ES loss or damage by incentivising their protection or production (Jack et al. 2008). As payments are linked directly with production of the desired service, this approach is considered more effective when compared to more traditional conservation efforts which link supports to area or management measures (Ferraro and Simpson 2002). At EU level, the value of such payments in the protection of ES is recognised in both forest and biodiversity policy documents (European Commission 2011, Forest Europe 2011).

Numerous definitions of payments for ecosystem services (PES) can be found in the literature, but one of the most cited is from Wunder (2005) who describes a PES as "a voluntary transaction where a well-defined ES is being 'bought' by a ES buyer from a ES provider if and only if the ES provider secures ES provision". However, this definition has been recognised as being too narrow, in particular given that it refers to "voluntary" transactions (Schomers and Matzdorf 2013). Although this is a necessary characteristic of any scheme developed in a country with well-defined private property rights, it may only relate to the payment mechanism itself. In reality, many PES schemes involve government regulation that requires behavioural changes or participation, particularly from the buyer's perspective (Vatn 2010). Sellers too may be placed within the 'market' involuntarily. In Europe for example, land-owners in Natura 2000 areas (such as special areas of conservation) are generally obliged to comply with certain restrictions and may be automatically enrolled in environmental payment programmes and thus, are not voluntarily sellers (Sattler and Matzdorf 2013). Landowners within such sites in Ireland are obliged to adopt certain measures and could seek financial compensation through the appropriate scheme (the AEOS/Natura 2000 scheme has been in operation since 2011 to replace the Rural Environmental Protection Scheme (REPS)) or directly from the National Parks and Wildlife Service. A broader definition of PES is offered by Mercer et al. (2011) who recognise PES as "formal and informal contracts in which landowners are remunerated for managing their land to produce one or more ecosystem service; PES transactions must consist of actual payments between at least one willing buyer and one willing seller to produce or enhance a well-defined ecosystem service or bundle of services." Under this definition, payments can come into existence through traditional public-funded land-use policies or by introducing private funding through the introduction of suitable legislation and the establishment of new markets or through voluntary purchases. Although the terms "market" and "market-based mechanisms" are often used in regards PES, it is important to note that such schemes rarely if ever occur in a true market environment, but rather adopt some of their principles (Wunder 2013).

This paper gives an overview of some of the most important, forest related, forms of PES available in the USA. In addition, the benefits and challenges of adopting such an approach in Ireland are discussed, with emphasis on smaller, private owners. This research stems from a literature review and a series of unstructured interviews conducted between June and November 2014 in the Pacific Northwest of the USA. Interviews were conducted with a range of individuals including non-industrial and industrial forest owners and managers, representatives of a number of forest and environmental NGOs with staff of the USDA Forest Service, US Fish and Wildlife Service (USFWS), and Oregon Department of Forestry (ODF). Interview questions were generally open-ended and focused on the history, drivers and management of specific forest-related PES schemes. The literature review and interviews were used to develop an understanding of these schemes from the perspective of both the regulatory authorities who oversee them, and the NGOs and landowners who implement them. The following review uses this information to describe the development of the main PES schemes in the USA and presents a number of examples of their implementation, primarily from the Pacific Northwest.

Markets and Payment Programmes in the USA

The USA has been actively developing private markets for certain services and has a range of publicly funded schemes that focus on the production of specific benefits (Mercer et al. 2011). In contrast, approaches in the EU tend to rely on traditional practice-based regulations and incentives (e.g. area based management or land use restrictions) that are publicly funded. However, a number of examples of PES exist in the EU and their continuing expansion is expected (Maes et al. 2013). In general, PES can be divided into, regulatory or compliance driven markets and voluntary markets, including publicly-funded schemes (Table 1). Perhaps the most well-established USA example of a market-based approach to conserving ES is wetland mitigation banking which requires developers to offset damage to wetlands and habitats by purchasing credits linked to comparable areas offsite. Water quality trading, which in Oregon is often based on temperature, has increased as an approach to enhancing water quality in fish bearing streams. Voluntary carbon markets have existed in the USA for some time but the recent establishment of the Californian regulatory market has created a large and, thus far, stable market for carbon. More traditional publicly-funded schemes are increasingly focusing on specific services rather than broader management linked goals (Mercer et al. 2011). However, many also recognise that properly managed lands can produce multiple services and achieve greater economies of scale (Deal et al. 2012).

Conservation easements

One of the most important legal mechanisms underlying many PES are conservation easements (CE), which may be viewed as a form of PES in themselves. An analogy often cited when describing property in legal terms is that of a bundle of sticks, with each stick representing a separate right which can be removed or sold individually.

Table 1: *Overview of the main PES schemes in the USA.*

	Payment for Ecosystem Service	**Focus**
Regulatory	Wetland mitigation banking	Wetland habitats
	Species conservation banking	Habitats for endangered and threatened species
	Water quality trading	Chemical, biological and physical measures of water quality
	Carbon sales - California	Carbon sequestration, climate change mitigation
Voluntary	Federally funded schemes	Multiple goals, some linked to habitats for endangered and threatened species
	Carbon sales - over the counter	Carbon sequestration, climate change mitigation
	Conservation easements	Multiple goals laid out in a legally binding management plan

Conservation easements essentially remove the ability to develop land in the future by placing this right in the hands of a land trust or state agency. Rather than selling ownership of the land a private owner can sell or donate the development rights on their property, while maintaining ownership and often the right to continue to manage the land in a specified manner. Recent decades have seen an approximately 25-fold increase in the number of easements currently held in the USA, which now cover approximately 16.2 million ha (U.S. Endowment for Forestry and Communities 2015). The history of conservation easements dates back to the 19th century and initially they were used to protect public parks. However, the goal of CEs now covers a range of benefits including, but not solely, biodiversity or habitat conservation. For example, working forest CEs have been established where forests can continue to be managed for timber production following a given management plan but cannot be altered otherwise e.g. conversion to agricultural land or other land uses, sub-division of the land or intensification of harvesting.

The Nature Conservancy is one of the largest environmental organisations in the USA and established the Working Woodlands Program in 2006 in Pennsylvania (The Nature Conservancy 2015). The organisation works with landowners to develop a 100-year management plan that combines timber, carbon sequestration and conservation goals. In addition, the plan meets FSC standards and owners can certify their timber as sustainable. Landowners benefit by gaining access to voluntary carbon markets and a low cost route to SFM certification while attaining a quality inventory and management plan and continuing to sell timber from their lands. A company specialising in carbon markets is a programme partner and assists with selling carbon offsets through the VCS (Verified Carbon Standard) registry. A conservation easement linked to the management plan underlies the programme.

Although restrictive, CEs offer a number of benefits to landowners. Landowners may be interested in maintaining their land in a certain condition due to their own sense of stewardship or due to their emotional attachment to it (Ma et al. 2012). An easement provides stability and certainty that their property will be preserved. However, landowners can also benefit financially from CEs. Although easements are normally donated, they can be sold to a land trust, or other NGO, or a public agency. Landowners can also benefit from a range of taxation measures depending on whether they donate or sell the CE and the tax laws of their state. These can include deductions in federal and state income taxes if the CE is donated (these may be spread out over a number of years, up to 15 in Oregon) and reductions in state property tax (based on the reduction in land value as a result of selling the development rights). From the purchasers' perspective, who are generally trusts or NGOs, they can ensure their mission or goals are being met without the associated costs of purchasing or buying land outright. Many organisations also have the support of rural communities as part of their mission and may wish to see the continued commercial management of land to support employment. In some circumstances, federal agencies will provide financial support for NGOs to purchase easements, e.g. an NGO raises 20% of the cost and the remainder is contributed by a federal agency.

Wetland mitigation banking

Wetland mitigation banking (WMB) is the most well-established of the markets for ES in the USA and involves the sale of wetland credits (this can include wetlands, riparian areas and streams) from bankers to developers to offset losses by land disturbances. This approach to conservation stems from the Clean Water Act (CWA) of 1972 that stipulates that there can be "no net loss" of wetlands, thus leaving potential for the development of offsetting. In particular, one section (Section 404) requires the attainment of permits for the discharge of material into wetlands, which can have requirements attached to them, giving significant power to the regulatory agencies. Although the Army Corp of Engineers (ACE) and the Environmental Protection Agency (EPA) are the agencies tasked with regulating the Clean Water Act and the associated banking system, the US Fish and Wildlife Service (USFWS) has played an important role in supporting and developing the programme.

Damage to wetlands generally takes place as a result of drainage or infill for purposes such as transportation infrastructure construction by state agencies or, commercial or residential development. Developers may be able to mitigate loses within a development property itself or may be able to offset the damage through an in-lieu fee payment to a governmental or non-profit agency, but if not, they must purchase credits from a bank. Sellers must create, restore or enhance (conservation is accepted in some circumstances) a wetland to develop a bank and sales can only take place within a specified service trading area, generally the watershed in which the loss is taking place. The EPA and the ACE issued guidelines in 2008, which specified that banking was the preferred approach to mitigation, giving explicit support to the banking system (ACE and EPA 2008).

From a developers perspective one of the major advantages of the system is the transfer of liability, and the associated costs, to a third party (the banker) who specialises in wetland management. Regulators view banking as a more effective way of conservation than on-site mitigation as the bankers have a stronger incentive in maintaining the wetland and more experience than the developer. The ACE maintain the RIBITS (Regulatory In-lieu fee and Bank Information Tracking System) website which in November 2014 contained over 2,000 banks. It is estimated that the annual value of these banks was between \$1.3 and \$2.2 billion in 2008 (Ecosystem Marketplace 2008).

Forest harvesting is one of the activities that is exempt from the permit requirements of Section 404, although the impact of forest activities on water may be addressed through regional plans agreed by the EPA and individual State forest-practices legislation. However, forest owners may be able to become wetland bankers if they possess suitable sites on their property. This may be particularly relevant to large industrial owners who possess areas that are considered unproductive from a commercial forestry perspective. For example, Weyerhaeuser, one of the largest timber companies in the USA, sells wetland banks in the southern United States (Weyerhaesuer Company 2015).

<u>Species conservation banking</u>

Species Conservation banking (SCB) is a more recent development but stems from the development of WMB and adopts a similar approach. The 1973 Endangered Species Act (ESA), which is administered by the USFWS and National Oceanic and Atmospheric Administration, is the primary driver of this form of banking. Although the Act does not specifically identify banking as a mitigation measure, it does recognise that habitat conservation and enhancement can occur "off-site". In addition, the ESA recognises the need to compensate private landowners and establishes a grant to assist states to fund projects that benefit listed species on non-federal lands. The USFWS published a "Guidance for the Establishment, Use, and Operation of Conservation Banks" in 2003 which is employed in their role in overseeing the development of banks.

Under the ESA, it is illegal to take a listed species, where "to take" is defined as "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct" and "harm" includes "significant habitat modification or degradation". Thus, the law has the potential to significantly affect land-use practices that have the potential to impact habitats of endangered species (Lueck and Michael 2003). However, in an effort to introduce some level of flexibility into the law an amendment was introduced in 1983 which allowed landowners and developers to be issued with an incidental take permit, i.e. permission to impact on a species, where they were undertaking a lawful activity and had developed a habitat conservation plan. One of the reasons this amendment was introduced was to encourage innovation in approaches to conservation (Mills 2003).

Similar to WMB, SCB is a form of off-site mitigation (i.e. that the damage from development is offset by conservation efforts in a different location) and bankers can create credits through the conservation, enhancement, restoration or creation of a suitable habitat.

Credits are specific to a particular listed species but can refer to (USFWS 2012):

1. An acre of habitat for a particular species;
2. The amount of habitat required to support a breeding pair;
3. A wetland unit along with its supporting uplands;
4. Some other measure of habitat or its value to the listed species.

The USFWS has approved over 105 banks for 60 threatened and endangered species across more than 90,000 acres of land (USFWS 2014). Bankers may be any landowner, including private owners, commercial and non-profit organisations and state and federal governments, although federal lands generally face greater existing regulation. For both WMB and SCB, bankers are generally obliged to transfer a conservation easement to an eligible third party, to develop a long-term management plan for the land and to establish a non-wasting endowment to fund the long-term monitoring and management of the site.

Water quality trading

Water quality trading or payments are some of the most recently developed markets for ES in the USA. The primary driver for this market is also the CWA, which requires any non-residential point source of pollution to acquire a permit to discharge into "navigable waters". The CWA identifies minimum standards, which may be biological, physical or chemical in nature, that must be met but individual states can set more restrictive limits. Thus, the political and regulatory system in place in a state can influence the number of water bodies considered impaired and different pollutants may be emphasised in different regions. For example, in the Pacific Northwest water temperature is considered a particular issue due to its potential impact on anadromous fish, including the seven salmon and trout species (*Oncorhynchus* spp.) native to the region which are considered of particular economic and cultural importance. Industries that use water for cooling purposes must attain discharge permits which generally require discharged water to meet a standard limit on temperature.

Utilities, such as power plants, are one of the major users of water for cooling. Water leaving a station is measured at the outflow before it enters a water body to ensure it meets a given temperature standard, which may be season specific. These standards are developed in relation to the maximum thermal daily load, essentially the maximum temperature input that doesn't significantly impact on biodiversity. Where standards are breached they may be required to build infrastructure, such as holding lakes and cooling towers, to meet the temperature guidelines. An alternative approach would be to reduce temperature loads in other parts of the river or water system to offset the impact of the discharge. In this context, a limited number of water quality trading programmes have been established in the USA. This involves utilities gaining some flexibility in how they meet water temperature targets by having landowners in the same watershed establish riparian woodlands to shade water bodies rather than employing a hard engineering solution.

Clean Water Services was the first water utility to be issued with a permit that included such an approach to dealing with effluent in 2004. The company manages waste water treatment in a watershed close to Portland, Oregon and would have faced costs of between $60 and 150 million to construct refrigeration units to cool water before releasing it into the Tualatin River. Under the permit, the utility was able to use riparian planting and flow augmentation to reduce overall stream temperatures rather than building new infrastructure. This alternative approach was estimated to cost $4.3 million for riparian planting along 35 miles of river (Cochran and Logue 2011). In addition, this approach provides a number of other benefits such as enhanced habitat provision. The Freshwater Trust (TFT) is one organisation that receives payments from utilities to work with landowners in establishing riparian vegetation. Rather than measuring the impact of the restoration directly, reductions in water temperatures are modelled using a tool, developed by the Oregon Department of Environmental Quality, which accounts for location and the width and height of vegetation adjacent to water bodies. Remote sensing, including the use of LIDAR, plays an important role in measuring the current conditions of the riparian areas. The reduction in temperature is modelled, comparing the current state with the expected reductions at the point of vegetative maturity, and the utility pays TFT based on a per-kilocalorie-reduction basis. The Trust, in turn, leases land for an annual fee from private landowners for a 20-year period and establishes native riparian vegetation, including cotton wood, alder and willow species (*Populus*, *Alnus* and *Salix* spp.). Some landowners are motivated by a sense of stewardship and a desire to see invasive species removed and do not require payment for leasing the land. After the 20-year period existing legislation protecting riparian forests will ensure that protection is permanent. This programme is described as trading as it offsets the impact of point sources of pollution, such as industrial wastewater, by reducing the impact of non-point sources, such as poorly vegetated riparian areas. Although the impact of these measures will only be quantifiable in the future as vegetation develop, TFT estimate that non-point sources account for 86% of the current thermal load on rivers in Oregon. This suggests that there is significant scope to counteract point sources of temperature through appropriate management of riparian areas.

Carbon trading

Markets for carbon emission trading are now the largest environmental markets globally (Newell et al. 2013). The USA lacks national policies around carbon offsets and trading but a number of voluntary carbon markets have been established with varying degrees of success. California has recently introduced a cap-and-trade system managed by the Air Resources Board (ARB) and carbon offsets have been traded through the system since 2013. Forests carbon credits can be generated for sale in this regulatory market system through reforestation, avoided deforestation and/or improved management, but only a limited number have been developed to date. A similar process is adopted in both voluntary and regulatory markets with sellers following an accepted protocol which sets out the process by which carbon is measured and how management impacts sequestration. The ARB protocol was developed from that of the Californian Climate Action Registry, a non-profit registry established in 2001 that specialised in emissions accounting. The Californian market is a regulated market, with price controls and is open to sellers across the USA and has links to Canadian markets. Price controls include a floor price, starting at $10, and ceiling prices (at which point supply is increased), starting at $40, both of which rise by 5% plus inflation per annum (Newell et al. 2013).

Voluntary carbon markets have been in place for some time in the USA and vary from complex agreements across industries or regions to over-the-counter sales between willing buyers and sellers. One example of the latter, of particular relevance to Irish forest owners, is Woodlands Carbon, a company established by the Oregon Small Woodlands Association (OSWA) to assist small, non-industrial forest owners to enter the carbon market. The process of measuring carbon for any credit is specific to the protocol being adopted and Woodlands Carbon employs a variation on the American Carbon Registry which compares an initial inventory to a baseline of standing carbon, based on regional data from the USFS Forest Inventory and Analysis data. Owners can sell the difference between what they currently have and what forests in this region would be expected to have. However, once sold the level of carbon is required to be maintained over the lifetime of the project. Additional carbon can be sold essentially as the difference between growth and harvesting but landowners must maintain a buffer of 15-20% of their carbon pool to account for unintentional reversals. The protocol developed for OSWA differed somewhat in that the credit was based on net-present value (using a 5% discount rate) and linked to the loss of value that would be endured as a result of a change in management practices. The first Woodlands Carbon sale involved 11 owners and was purchased by a broadband company in Oregon.

Federal funded schemes

Schemes to plant forests on agricultural land have been in place in the USA for a number of decades, but the goals and design of such schemes has changed considerably over time and landowners can currently avail of an array of different supports for both afforestation and forest management (Mercer et al. 2011). Generally forest related federal schemes are funded by the Natural Resources Conservation Service (NRCS) under the Farm Bill.

The Healthy Forest Reserve Program was an example of a voluntary conservation programme under the 2008 farm bill established to encourage the production of ecosystem services (including the protection of listed species, carbon sequestration and forest health) from private forests. The NRCS oversaw the programme and worked with other agencies, both state and federal, in developing initiatives to promote the conservation of endangered species on private lands. For example, in Oregon the USFWS and ODF developed programmes aimed at northern spotted owl (*Strix occidentalis caurina*) habitat on private lands. Safe harbour agreements granted landowners some flexibility in how they managed their lands if they agreed to follow a management plan that they developed with the technical assistance of the agencies. Plans included a range of measures, such as longer rotations, which would enhance the services provided by the forests. Under the agreement the plans could be followed even if a new population of an endangered species was established. This meant that landowners would not be prosecuted for "taking" a listed species as long as the management plan was followed, i.e. it was assumed that the forest would provide a net benefit in terms of conservation even if a single specimen was impacted. Under the legislation, landowners had to enter the land into a CE which specified the management approach to be adopted and payments were made to landowners based on the length of the CE. For a permanent easement landowners could receive a payment equal to 95% of the full value of the land while maintaining a right to harvest timber from the forest.

Drivers of Payments for Ecosystem Services (PES)

Markets for ES can be created through environmental regulation or through private or commercial attempts to offset damage and enhance benefits motivated by ethical concerns and/or reasons related to corporate social responsibility and marketing. Payments may come from national or state governments, commercial and non-profit organisations or private individuals. The specific design of a payment scheme will be influenced by the nature and importance of the service of interest (Jack et al. 2008). One of the aspects of PES which has helped to create significant interest in such policies has been the recognition of achieving multiple beneficiaries and potential "win-win" scenarios where environmental improvements can be attained while minimising restrictions on economic activity (Engel et al. 2008). In reviewing the formation of PES a number of essential drivers are evident, as described below.

Supportive and innovative regulatory authorities and NGOs

The most established USA markets were created primarily as a result of regulatory authorities seeking innovative solutions to the challenge of implementing legislation. Agencies, such as the EPA, which are tasked with overseeing particular pieces of legislation, have to be supportive of the concept for some markets to be established. In addition, funding for the development of markets and the associated infrastructure often stems from public sources. Organisations which are viewed as independent and non-regulatory, such as NGOs, often play an important intermediary role between landowners and buyers. In addition, NGOs and representative groups can assist in the formation of cooperatives to enable smaller landowners to access markets, as was the case with Woodlands Carbon.

Recognition and quantification of ecosystem services

To link payments to outcomes, the services that flow from a particular location and the impact of management must be recognised, which may include multiple services or benefits (Deal et al. 2012). Information and tools that facilitate the quantification of ES are an essential part of any system as it is rarely possible to measure services in real time (Jack et al. 2008). This can be seen clearly in water quality trading where payments are linked to the expected reduction in thermal loads modelled using a tool developed at the state level.

Regulation, information and education

Some PES have a clear link to regulation, including mitigation banking and water quality trading which both stem from national legislation. One of the essential elements of this legislation is a recognition that some form of off-site mitigation can occur and, in terms of wetlands, that the goal is no net loss rather than strict conservation in-situ as stated in the CWA. Such an approach to target setting, particularly for biodiversity, is currently being reviewed at an EU level (European Commission 2015). The adoption of no net loss targets would offer the potential to develop mechanisms for forest owners to trade habitats on their land. No regulatory carbon market for Irish forest carbon credits currently exists as they are excluded from the EU Emissions Trading System. Voluntary carbon markets can be viewed as being information driven as an increasing awareness of the impact of carbon emissions underlies their creation, rather than a regulatory requirement. However, this market appears to be relatively limited in Europe. A first step in their creation would be the development of protocols that outline how credits can be generated, bought and sold, and how the market can be managed, including the identification of the key agents in the process.

Motivated buyers and sellers

Buyers in US PES schemes generally come from industry or the public sector rather than private individuals (Engel et al. 2008). Some buyers may be direct users of an ES, such as a water company who pays upstream owners to manage their lands to enhance water quality, or indirect users, such as factory owners that purchase carbon credits. Other buyers include NGOs and government agencies that are tasked with the protection or enhancement of ecosystems. Aside from regulatory requirements, private sector purchasers may be motivated by a desire to reduce regulatory risk in the future by demonstrating the effectiveness of self-regulation (USFWS pers. comm.). This is most clearly demonstrated in conservation banks which are aimed at ensuring the protection of species to avoid their listing as threatened or endangered. Buyers may also desire to enhance their reputation and image for marketing reasons.

Sellers can come in a number of forms but are often limited to smaller private owners in federal funded programmes. Many private non-industrial sellers of ES may be motivated by a conservation ethic rather than a profit motive. Smaller private owners may be constrained from entering some markets directly, such as conservation banking, given the significant upfront investment required, which could potentially be greater than the resulting payment (Wunder 2013).

Potential benefits of PES schemes

One of the primary arguments in favour of PES is that conservation aims can be met more efficiently following set goals that are delivered in a targeted way based on where the highest value or lowest cost exists (Ferraro and Simpson 2002, Jack et al. 2008). From the perspective of regulatory agencies, PES schemes such as mitigation banking may be a preferred method of conservation as it requires the permanent management and protection of a habitat (ACE and EPA 2008). Mitigation, either on- or off-site, by developers may not produce the same outcome as they lack a long-term incentive. From the developer's perspective, purchasing an offset may speed up the licensing process and be more efficient than undertaking mitigation directly. Such an approach may also ensure that those involved in the exchange have higher levels of knowledge and information than traditional regulatory approaches (Engel et al. 2008).

The willingness of landowners to supply services through active management or conservation is essential to protecting ES on private lands (Ma et al. 2012). In addition to rewarding owners for good practices, PES may help landowners to diversify their incomes and bring greater economic resilience to smaller landowners and rural economies (Jack et al. 2008). More generally, regulators often refer to the ability of PES to turn a perceived liability into an asset, e.g. possessing an endangered species on a property could be viewed as a means of increasing income rather than as a threat to the livelihood of the landowner (USFWS pers. comm.). Some USA landowners were viewed as having a negative view of regulations related to listed species in the past, particularly those that were seen to have a direct impact on their industry. Overly burdensome and costly regulation related to endangered species may result in some landowners attempting to remove the species from their property to avoid the problem, colloquially termed "shoot, shovel and shut-up" in the USA (Lueck and Michael 2003). Incentivising conservation with payments can, at least, address some of the associated costs. Tax-payers may also benefit from PES as conservation efforts may be more targeted and, in some cases, acquire funding from private sources rather than relying solely on public funds. A more general consumer benefit which may exist, but is difficult to quantify, is the influence of ES on the costs of electricity, water and consumer goods. Service providers must frequently resort to hard engineering solutions to ensure a quality service or to meet environmental or health guidelines. If landowners can be paid to deliver services that provide the same benefits at lower costs, as in the Clean Water Service example described previously, consumers may benefit.

PES schemes often provide benefits beyond the service they are targeting and thus multiple services may be enhanced through one payment (Deal et al. 2012). Although forest related PES may be viewed as having a negative impact on timber production, this may not always be the case as payments may stem from land that was already unproductive. For example, carbon sales may be made from conservation areas or riparian buffers which were already restricted in terms of timber harvesting. More generally sales of ES may be possible from forests which may not be harvested profitably due to high operational costs. Non-forest lands may be sold separately to provide new habitats, such as through wetland mitigation banking, which can produce an income from lands which would have been considered as unproductive otherwise. Thus, markets may be created for the conservation of lands which would not have generated income otherwise. Carbon credits may be created through an extension of the rotation age which may increase timber production, particularly of sawlog (Pohjola and Valsta 2007). The landowner would thus receive compensation for delaying timber harvesting while production overall could be greater.

PES in Ireland

From an Irish perspective, only publicly funded payments for forest services have developed thus far. In addition, these payments are rarely based on the provision of a service but rather on land use change or forest management practices. PES schemes, in theory, achieve greater efficiencies in terms of the production of ecosystem systems as they link the quantity of payments directly to the quantity of benefit produced. This has the advantage of ensuring the desired outcome is actually achieved. The existing afforestation scheme in Ireland can be considered a PES under some definitions as it recognises that multiple services flow from the forest estate (economic, social, environmental and recreational benefits), but payments are linked to land-use change rather than service delivery. Landowners receive funding based on the area planted, irrespective of whether they produce a given service or not. It is important to recognise that the development of PES in the USA took a number of decades and the introduction of such systems in Ireland could face a number of challenges including:

Achieving additionality

An important issue in any PES scheme is whether the programme is achieving true additionality beyond what is already required by law. One of the criticisms of the REPS, which focused on agricultural land in Ireland, was that it was difficult to prove that genuine improvements had been attained beyond what is achieved by standard management following existing regulations (Hynes and Murphy 2002). The forest environmental protection scheme did attempt to deliver multiple benefits through active management linked to specific practices but its success in achieving this has not been measured. The renewed Native Woodland Scheme requires the creation of specific woodland habitats based on site and soil suitability, an approach which places greater emphasis on the outcome of the policy. Although the theory of PES suggests linking payments to services, it should be noted that in practice payments are often area based as the quantification and surveillance of services poses a serious challenge (Engel et al. 2008). However, baseline inventories of existing service levels are required to identify any subsequent increases. In addition, a standardised method of measurement, such as those contained in carbon offset protocols, ensures transparency and equality in the quantification of benefits. Such concerns should be accounted for in the design of a PES scheme. Related to this, the mapping of ES is a growing area of research as location can play an essential role in understanding both the supply and demand of services (Maes et al. 2013). This could be integrated into the afforestation scheme by varying payments based on the supply of ES from a given location, as in the now-closed Woodland Grant Scheme in England (Forestry Commission England 2015) and the Forestry Grant Scheme in

Scotland (Forestry Commission Scotland 2015).

One of the major challenges for private landowners to achieve additionality is that legislation already protects the production of services to some degree. Any move towards more outcome-based payments would have to account for existing forestry and land-use policies to ensure that direct policy conflict does not arise (Jack et al. 2008). Many countries, including Ireland, impose restrictions on converting forest land and on how management is undertaken. Where such legislation is in place, landowners have already been obliged to absorb the costs of supplying ES to some degree and potential buyers are unlikely to pay for something which is already being produced.

Significant costs associated with sales

As previously discussed, even where a market exists, creating credits for sale can be costly. For wetland and conservation banking, bankers must initially undertake the restoration work but are also obliged to establish a non-wasting endowment to pay for their on-going management. Most schemes require an extensive inventory for the services to be initially quantified, which can involve employing a number of specialists. Where new markets are being established, protocols must be developed or management baselines must be described so that the expected increase in services can be quantified. In addition, there is often a requirement for third-party verification of service provision. Such costs are often a significant barrier to market entry by smaller owners and may require support by public agencies or NGOs.

Landowner ethic

It is recognised that forest owners are motivated by a range of factors and rarely focus solely on profit maximisation, which is considered to be one of the major challenges in promoting afforestation in Ireland (Howley 2013). Although PES may appear to be turning a liability into an asset, from the landowner's perspective a more important issue may be a loss in lifestyle or freedom of management rather than maximising income alone. Smaller forest owners in Oregon who have engaged with PES schemes have generally done so for ethical rather than commercial reasons (OSWA pers. comm.).

A related challenge faced by small private owners in entering environmental markets is the long-term nature of the restrictions. For example, carbon projects in the Carbon Action Reserve must enter long-term agreements, typically 100 years, from the year the specific carbon credit is sold. However, Woodlands Carbon was able to develop a protocol that required a shorter commitment period for small owners in Oregon. In addition, although restrictions may be long-term or even permanent, payments may take place only once. Research into the willingness of private forest owners to engage with PES schemes would be valuable in ascertaining the potential level of supply and how such schemes should be designed.

Conclusion

PES can offer the potential to create additional income streams for forest owners and allow them to receive compensation for adopting less intensive management practices. Payments and markets for forest-related ecosystem services have existed in the USA for a number of decades and are increasing. Wetland mitigation banking is now well-established and recognised by regulatory authorities as a preferred form of mitigation. Conservation banking protocols have been developed for a number of species and new ones are under development. Water quality trading highlights directly the value of riparian woodlands in protecting and cooling water. The Californian cap-and-trade market has expanded the potential market for carbon credits beyond the existing voluntary markets. The size of these markets is expanding, but given the cost and complexity of entering many markets, questions exist as to how attractive they are to smaller private owners. Meanwhile industrial forest companies and NGOs appear to be amongst the primary beneficiaries.

Amongst the lessons Ireland might learn from this approach to conservation is the need to recognise and actively quantify forest-related ecosystem services. The potential exists to engage private industry in supporting PES schemes through appropriate legislation or the creation of voluntary markets. Regulatory authorities will play a central role in this process through the manner in which legislation is designed and enforced and by actively supporting market development. More generally, adopting a more outcome-based approach to supporting the production of services has the potential to achieve greater efficiencies and to benefit landowners, industry and citizens.

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Appendix – Abbreviations used in this paper

ACE	Army Corp of Engineers
ARB	Air Resources Board
CE	Conservation easement
CWA	Clean Water Act
ES	Ecosystem services
ESA	Endangered Species Act
MEA	Millennium Ecosystem Assessment
NRCS	Natural Resources Conservation Service
ODF	Oregon Department of Forestry
OSWA	Oregon Small Woodlands Association
PES	Payments for ecosystem services
REPS	Rural Environmental Protection Scheme
SCB	Species conservation banking
TFT	The Freshwater Trust
USFWS	US Fish and Wildlife Service
WMB	Wetland mitigation banking

The potential availability of land for afforestation in the Republic of Ireland

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Abstract

The Irish Government reiterated its commitment to expand the productive forest area to 18% of the land area by 2046 (DAFM 2014) in order to maintain a sustainable processing sector with its many additional benefits. The process of increasing afforestation rates may also offer significant scope to mitigate greenhouse gas (GHG) emissions, especially from agriculture, which is expected to expand production to cater for increased demand for food and fibre. The challenges of managing multiple conflicting land use objectives (aimed at both increasing food and fibre production as well as trying to maintain conservation values) and their effect on land availability for forestry expansion are examined in this paper. An assessment was made of the land resource available for afforestation and the related opportunities and constraints are discussed. Results indicate that 4.65 million ha of land in Ireland are potentially suitable for forestry; of this 896,880 ha are subject to national and EU designations where existing habitat conservation is prioritised. Of the remaining 3.75 M ha, 2.42 M ha are classed as productive agricultural land, likely to be the main focus of agricultural expansion. The remaining 1.3 M ha, classed as being marginal for agriculture, shows significant scope for afforestation. To assist in the achievement of forestry targets, it may be necessary to consider all sources of land, including a significant area currently under-utilised (unenclosed land), more than a third of the target planting area (c. 178,000 ha), as well as the development of native woodlands that may also fulfil conservation and carbon sequestration objectives.

Keywords: *Land use, afforestation targets, conservation, agricultural land use.*

Introduction

Opportunities and challenges to forestry expansion

Forestry expansion has re-emerged at the top of the land use agenda in Ireland, driven by two contemporary challenges: (1) the need to produce enough fibre to create a sustainable processing sector and (2) the sustainability of agricultural intensification and the achievement of a carbon neutral agricultural sector by 2050 (Schulte et al. 2013, O'Brien et al. 2014). Reflecting these challenges Government policy has reiterated its commitment to expand the productive forest area to approximately 1.25 million ha or 18% of the land area (DAFM 2014). This would require annual afforestation targets of 16,000 ha yr^{-1} to 2046. Whether such planting rates are possible is very uncertain, particularly given the recent decline in afforestation from 23,000

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ha yr^{-1} in 1995 to just over 6,200 ha in 2013; significant efforts will be necessary to stimulate land-use change and increased forestry expansion. While the availability of funding for forestry expansion and recent budgetary constraints undoubtedly have had a significant impact on the expansion of new forest planting, the availability of land will ultimately limit forestry expansion, owing to the array of competing land uses, including planned expansion in the agricultural sector and constraints posed by conservation policies and objectives. Since 4.9 million ha are currently in agricultural use (CSO 2012), future forestry expansion will disproportionally depend on a change in land use from agriculture to forestry. The quality of land is a defining aspect in the decision-making process by farmers (Ní Dhubháin and Gardiner 1994, Howley et al. 2012). Land marginal to economic agriculture represents a viable prospect for such land use and many landowners (18,000 since 1980 (Ní Dhubháin et al. 2010)) have availed of incentives such as grant and premium payments to convert agricultural land to forestry. Where land is of better quality and suitable for a wide range of agricultural enterprises, such as in livestock, tillage and horticulture, forestry becomes a less attractive option since returns in forestry are often lower than in competing agricultural enterprises (Upton et al. 2013). The issue of personal choice also influences the outcome. Farmers, for various reasons of lifestyle choice, lack of familiarity with forestry, family tradition, or the perception that "good land" should remain in agriculture, sometimes do not consider forestry as a land-use option.

Despite these challenges there is still an interest among policy makers in a continued expansion of the forest resource with the aim of developing a more sustainable sector that provides many additional benefits (i.e. production of raw material, expansion of the processing sector, recreation, etc.). One of the main drivers of forestry expansion in Ireland over the last number of years has been the capacity of post 1990 "Kyoto" forests to sequester carbon. Including fossil fuel substitution, the sequestration potential for forestry is estimated to be 4.2 Mt CO_2 equivalent yr^{-1} by 2030 (Schulte et al. 2013). Recently the aim to achieve a carbon neutral agricultural sector by 2050 in Ireland has received much attention (Schulte et al. 2013). If this is to be achieved, it is likely to require a mosaic of solutions. These include an increase in carbon sequestration capacity by accelerating new forest planting above current levels (as well as correcting an unbalanced age-profile within the forest estate), advanced mitigation strategies, technology advancements and restrictions on production. The potential for increased sequestration through accelerated new afforestation shows considerable scope. While increased forest sequestration does not reduce national emissions, its full compensatory effect is disproportionally dependent on a balanced age structure so the achievement of higher planting rates is vital, at least over the next two decades.

Although creating a carbon neutral agricultural sector by 2050 in Ireland could be partially achieved by increased forest carbon sequestration and changes to the carbon accounting procedures, this may ultimately result in a competition for land for use in agriculture, or to help meet other environmental objectives. There is a high probability of additional land resources being required to support increased agricultural output, particularly following the phasing-out of EU milk quota by 2015 (Schulte et. al. 2014). However, policy makers are increasingly viewing forestry as an integrated land-use option, which will assist in the overall achievement of food and fibre security and support the sustainable intensification of the agricultural sector by helping to offset carbon emissions.

The knowledge gap

To help achieve current Government targets of 18% forest cover (DAFM 2014), an urgent acceleration of the afforestation programme is necessary, requiring the planting of 490,000 ha of new forests by 2046. Currently the afforestation programme is largely focused on encouraging the private sector to convert less productive agricultural land into forestry. To date, information on the availability of land resources to facilitate forestry expansion has not been available. There is a need to examine all current information to characterise the nature and extent of land availability and suitability for afforestation and quantify the various land use types and their potential suitability for forestry using soils and related spatial datasets. This information could then be used to assess the opportunities and constraints for forestry expansion. Similar research in Scotland, which has succeeded in identifying these opportunities and constraints, was carried out by the Woodland Expansion Advisory Group (WEAG) (Sing et al. 2013).

Certain constraints may limit or preclude forestry expansion or land use change for any particular parcel of land. It has been suggested that conservation policies related to habitats or species have reduced annual afforestation rates and discouraged applications in relevant areas (Collier et al. 2002). These include EU habitats (92/43/EEC) and birds (79/409/EEC) directives, in which conservation of existing habitats is prioritised. In addition, there are restrictions on the planting of coniferous forestry in acid sensitive catchments. Constraints relating to the types of land that can be planted, and its productive capacity, are likely to influence the potential area made available for forestry expansion. Land deemed suitable to receive financial support under the afforestation scheme must be capable of growth rates equivalent to a minimum of yield class 14 for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) (Forest Service 2012). Other constraints on the types of land include restrictions on the amount of unenclosed land that can be planted (lands generally used for extensive grazing, on which agricultural productivity is low currently) and will further reduce the potential pool of land for afforestation (Farrelly and Gallagher 2013). All these constraints, together with the predicted expansion in agriculture (e.g. the diary sector which expects to expand milk production by 50%), may result in considerably less land becoming available for future forestry expansion. This paper aims to provide information on the barriers to land availability for forestry in Ireland, which may ultimately limit the expansion of forest cover and the achievement of multi-sectorial goals. This expansion may result in an increase in competition for land with agriculture and necessitate a re-appraisal of the current administrative constraints on new forestry planting.

Objective

The overall objective of this study is to provide information on the potential availability of land for afforestation, and assess if limitations to land availability will ultimately constrain the expansion of the forestry area. The study seeks to identify the most likely areas to have potential for forestry expansion, given the increased importance of multiple land use objectives like agricultural expansion and conservation.

Data and methods

Spatial analysis techniques were used in this study to assess land-use using a Geographic Information Systems (GIS) and a series of the most up-to-date spatial datasets available on land-related activities (Table 1). The total administrative area of the Republic of Ireland (6,989 M ha) was derived from a boundary shape file map of the Republic of Ireland representing the terrestrial land area. The base map was converted to an ESRITM grid file raster map containing 6.989 × 108 pixel cells each representing a land area of 10 × 10 m. For certain datasets (e.g. energy utilities, road and railway infrastructure and buildings) a buffering technique was incorporated to allow for setback distances in which forests cannot be planted as per Irish Forest Service guidelines (Anon 2012). These setback distances ranged from 5 to 30 m either side of a road or building. Other datasets used included a shapefile of all forests in public and private ownership (correct up to 2008), land cover datasets (Loftus et al. 2002, Fealy et al. 2006), datasets relating to national and EU designations (e.g. NHA's, SAC's SPA's) and datasets related to water quality (potentially acid sensitive catchments and fishery sensitive areas), a soils and land use capability map for agriculture (Gardiner and Radford 1980) and a national forest productivity map (Farrelly et al. 2011). The GIS analysis method was similar to the approach used in Scotland by Sing et al. (2013) to evaluate the potential of land for tree planting and combines features from multiple datasets, and uses this information as the basis to classify land into the four categories based on opportunities and constraints for afforestation, as outlined below.

1: Land biophysically unavailable for forestry expansion

Land was designated as being biophysically unavailable for forestry expansion if it was composed of one or more of the following: existing forest cover, water, urban areas, energy utilities, road and rail infrastructure and buildings (Table 3; Figure 1a-e).

Table 1: *Sources of various data available on land use and related information used in the study.*

Data type	Data source	Year	Format	Primary processing unit (resolution m^{-2})
Administration boundary				
Republic of Ireland boundary	Ordnance Survey Ireland	2006	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Forestry				
Forestry parcels data	Forest Service	2008	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Woodland cover	Ordnance Survey	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Forest productivity data	Teagasc	2011	ESRI™ grid	ESRI™ Grid (10 × 10)
Water				
Water features	Navtech™ dataset	2011	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Lakes, ponds, reservoirs, river banks and centres	Ordnance Survey Ireland	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Urban areas				
Towns/urban areas/retail/amenity/beach/golf courses	Navtech™ dataset	2011	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Towns/military	Ordnance Survey Ireland	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Utilities				
Electricity pylons - ESB	Ordnance Survey Ireland	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10) + 30 m setback
Railway infrastructure				
Industrial and passenger rail	Ordnance Survey Ireland	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10) + 20 m setback
Road infrastructure				
Major and secondary Highways	Navtech™ dataset	2011	ESRI™ shapefile	ESRI™ Grid (10 × 10) + 20 m setback
Streets, fourth class roads	Ordnance Survey Ireland	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10) + 20 m, 5 m setback
Buildings				
Houses, once-off units	An Post Geo Directory	2006	ESRI™ shapefile	ESRI™ Grid (10 × 10) + 30 m setback
Other buildings	Ordnance Survey Ireland	2005	ESRI™ shapefile	ESRI™ Grid (10 × 10) + 30 m setback
Landcover data				
Landcover/habitat maps	Teagasc	2005	ESRI™ grid	ESRI™ Grid (10 × 10)
Environmental/conservation				
Special Areas of Conservation (Nature 2000 network)	NPWS data	2012	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Special Protected Areas (Natura 2000 network)	NPWS data			
Natural Heritage areas (NHA)	NPWS data			
Freshwater pearl mussel catchments (+ 6 km buffers)	Forest Service	2012	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Potentially acid sensitive catchments	Forest Service	2012	ESRI™ shapefile	ESRI™ Grid (10 × 10)
Agricultural land use data				
Soil association & Land Capability map for Agriculture	Teagasc	1980	ESRI™ grid	ESRI™ Grid (10 × 10)
Agricultural land use data (National Farm Survey)	Teagasc	2012	Summary statistics	n/a

2. Land biologically unsuitable for forestry expansion

Land was considered biologically unsuitable for forestry expansion if it included land incapable of producing a forest crop, such as intact raised bogs, fens, sand dunes, coastal complexes, salt marshes, rock outcrops and karst areas (Loftus et al. 2002) (Figure 1f). Areas deemed unproductive for forestry were also included here and were derived from a map of forest productivity of Sitka spruce in Ireland (Farrelly et al. 2011). Forest productivity is measured by the yield class (YC) system (Edwards and Christie 1981) and is the potential of a site in terms of the mean annual volume increment per hectare of a stand on that site up to a reference age. All land below the minimum needed for an afforestation grant aid, as per Forest Service requirements (YC 14 for Sitka spruce), was also classified as having no potential for afforestation.

3. Land affected by national and EU designations and policies

Land subject to national and EU designations and policies that may impose constraints to afforestation were calculated from a series of datasets of nature conservation designations and water quality objectives (Figure 1g; Table 1). These lands were not subject to category 1 or 2 constraints and were biologically suitable for afforestation, but were designated for protection under EU habitats (92/43/EEC) and birds (79/409/EEC) directives and other national conservation policies (e.g. natural heritage areas and nature reserves)[3]. Areas subject to specific water quality guidelines were also included using a dataset of potentially acid sensitive water catchments provided by the Irish Forest Service. Areas classed as being category 3 have limited scope for afforestation. Some areas in this category may be considered eligible for planting subject to specific conditions compatible with environmental guidelines or with specific approval by the Forest Service. For example, in potentially acid sensitive areas, commercial planting can be approved following the outcome of a laboratory test, while the native woodland establishment scheme is permitted without major restriction (see Anon 2012).

4. Land most likely to have potential for forestry expansion

This includes all lands likely to have potential for forestry expansion not in categories 1 to 3 Table 4). These areas are likely to have most potential for forestry expansion. Fishery sensitive areas are included here as, applications for afforestation grant aid are permissible subject to appropriate measures (which may be locally applicable to particular afforestation applications) together with adherence to the codes of best forestry practice. The land area within category 4 was then classified into productive agricultural land and marginal agricultural land according to Gardiner and Radford's

[3] Other areas outside of the main environmental constraint areas may have constraints for afforestation and subject to directives for water, habitat, birds, etc. These are not considered here but may be locally applicable to particular afforestation applications.

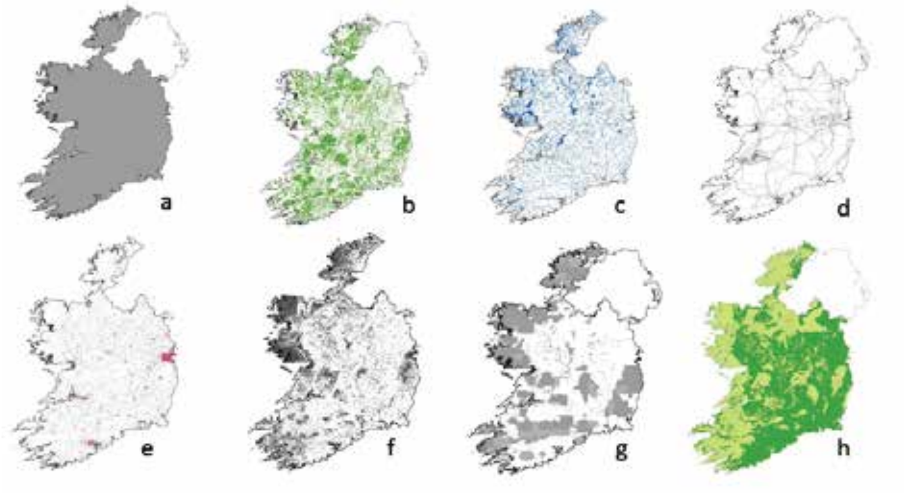

Figure 1: *Map resources used to derive the area potentially suitable for afforestation. Clockwise, (a) terrestrial land area –in grey; (b) forest cover; (c) water bodies; (d) road, rail and energy utilities; (e) urban; (f) unplantable/unproductive areas; (g) environmental constraint areas; (h) agricultural usage category (light green marginal agricultural land, dark green -productive agricultural land).*

(1980) map of soil suitability for agriculture, as described below.

Classification of productive agricultural land

Productive agricultural land was classed as having a wide usage range (class 1, 2 and 3, Table 2). Soils were deemed suitable for tillage and grassland according to Gardiner and Radford's (1980) land use potential of Irish soils, supplemented by data on the range of agricultural systems from the Teagasc National Farm Survey (Moran 2014). Generally, soils in this category were fertile, well drained and occur from the lowlands up to 150 m in elevation. Some small areas of poorer soils are often present due to the resolution limitations of the datasets used.

Classification of marginal agricultural land

Marginal agricultural land is land classed as having a limited usage range (class 4, 5, and 6, Table 2). These soils are moderately suitable for permanent pasture and not suited to tillage and are marginal for agricultural use (Gardiner and Radford 1980, Moran 2014). These soils have poor to moderate fertility and vary from well to poorly drained, occuring at higher elevations on steep slopes of mountain and hill sides or in drumlin areas. Peat soils are also present and the proportion of higher quality tillage land is low.

Assessment of potential forest productivity

The productivity assessment used here utilises data from Farrelly et al. (2011)

and land must have been capable of achieving a minimum growth rate[4] of YC 14. Forest productivity was divided into four categories; moderate, good, very good and excellent. Such categories represented the yield class bands 14-18, 18-22, 22-26 and 26+, respectively.

Trends in planting on agricultural land and national and EU designated areas
Datasets of forest cover provided by the Irish Forest Service covering all forests (both public and private) planted up to 2008 were used, to assess historical planting patterns on productive and marginal agricultural land and the land cover types planted. The level of planting on national and EU designated areas, classified here as category 3 constraint areas were also assessed. This may allow some inferences as to the likelihood of planting occurring on certain categories of agricultural lands, land-cover types and in national and EU designated areas.

Results

Area potentially suitable for afforestation
The outcomes of our analysis of land deemed most likely to have potential for afforestation are presented in Table 3 and Figure 2. An area of 1.49 M ha, 21.3% of the land area of Ireland, was classified as having category 1 constraints, being biophysically unavailable for afforestation (classified as forest, urban, water, road and rail, electricity utilities and buildings). Of the remaining 5.49 M ha, 12.2% (850,238 ha) are considered biologically unsuitable for afforestation (category 2). A further 12.8% (897,121 ha) of land was affected by national and EU designations and policies (category 3). The remaining land area with most potential for afforestation (category 4) covered 3.75 million ha or 54% of the area of the Republic of Ireland. While this land was deemed most likely to have potential for afforestation, taking the constraints mentioned above into account, it was not necessarily unconstrained for forestry expansion. Land cover characteristics show that nearly 95% of this land (3.57 M ha) was classified as grassland (dry grassland including tillage land, wet and reclaimed grassland) (Table 2). There were also smaller areas of other land-cover types typically associated with unenclosed land, including industrial cutover peat lands, heathland (with shallow peat and mineral soils) and flushed areas of bog not part of category 2 or 3 lands that showed acceptable YCs for afforestation (178,996 ha).

Potential forest productivity
The bulk of the area with most potential for afforestation (category 4 land; Tables 4 and 5) was grassland with 2.8 million ha showing very good to excellent potential for

[4] The pre-requisite for afforestation grant aid is based on the Forest Service requirement that the land must be capable of achieving a minimum growth rate of YC 14 for Sitka spruce with a standard application of fertiliser (e.g. 350 kg ha^{-1} GRP) at the time of establishment or from a split application (for full details see Anon, 2011).

Table 2: *Productive and marginal agricultural land in Ireland was classified by Gardiner and Radford (1980) into six soil suitability classes based on their potential for various agricultural systems.*

Use-range	Soil suitability class	Suitable agricultural systems
Productive agricultural land	1	Suitable for tillage, pasture, meadow and forestry
	2	Moderately suitable for tillage, pasture and widely suitable for forestry
	3	Moderate to poorly suitable for tillage; limited to moderately suitable for pasture, meadow and forestry
Marginal agricultural land	4	Poorly suitable for tillage; moderate to poorly suitable for pasture and meadow; moderately suitable for forestry
	5	Unsuitable for cultivation, meadow or intensive grazing; moderately suitable for forestry and extensive grazing
	6	Unsuitable for cultivation, meadow or intensive grazing; certain areas may be suitable for forestry

forest production with YCs in the 22 to 26+ range, the remainder of grassland shows good levels of production, having YCs ranging from 18 to 22. Of the area classed as unenclosed land, occupying 178,996 ha, 42% of the area (74,397 ha) showed good to excellent levels of potential production ranging from YC 18 to 26+, with the remainder of the area showing moderate levels ranging from YC 14 to 18 (104,600 ha).

Agricultural usage

The information gathered on agricultural use indicated that 65% of the land likely to have potential for afforestation (2.45 M ha) was classified as productive agricultural land (making it suitable for almost all agricultural enterprises). Almost all this area was identified as being suitable for tillage and grassland (2.42 M ha). Smaller areas of reclaimed and wet grassland were also present in this category representing <5% of the area. According to unpublished data from the Teagasc National Farm Survey in 2013, livestock-based enterprises predominated on these lands. The main enterprises were: cattle non-dairy (42%), dairy (25%), tillage (12%), sheep (12%) and mixed livestock (5%) (Figure 3). Farming of this category was profitable with average farm income calculated at €30,761 per annum per household in 2013 (Moran 2014). A small amount of poorer land (24,647 ha) on the margins of productive land, composed mostly of mineral soils with shrub heath, cutaway peat lands, flushed bogs, etc., are

Table 3: *Potential availability of land for forestry expansion in the Republic of Ireland.*

Category	Land use	Total area (ha)	% Ireland	Total per category
1: Land biophysically unavailable for forestry expansion	Forest	735,511	10.5%	1.49 M ha
	Other woodland	16,720	0.2%	(21.3%)
	Scrub	27,543	0.4%	
	Water	171,368	2.5%	
	Urban	160,966	2.3%	
	ESB	29,554	0.4%	
	Rail	8,115	0.1%	
	Public roads	118,684	1.7%	
	Buildings	223,467	3.2%	
2: Land biologically unsuitable for forestry expansion	Bare rock and outcrops	230,432	3.3%	0.85 M ha
	Coastal sands	5,928	0.1%	(12%)
	Raised bogs and fens	107,907	1.5%	
	Salt marsh	352	0.0%	
	Deep peat	298,014	4.3%	
	Heathland	61,985	0.9%	
	Unproductive	145,620	2.1%	
3: Land affected by National and EU designations and policies	Area designated for protection of hen harrier	54,399	0.8%	0.90 M ha (13%)
	National designations (Natura 2000 sites, NHA and Nature reserves)	180,632	2.6%	
	Fresh water pearl mussel (6 km priority catchment area)	362,507	5.2%	
	Fresh water pearl mussel (catchment)	146,522	2.1%	
	Potentially acid sensitive	153,061	2.2%	
4: Land most likely to have potential for forestry expansion	Non-fishery sensitive	3,259,524	46.6%	3.75 M ha
	- of which fishery sensitive	(490,894) a	7.0%	(54%)
Total land area		6,989,537	100%	

[a] Application of appropriate screening of forestry applications in fishery sensitive areas may be locally applicable.

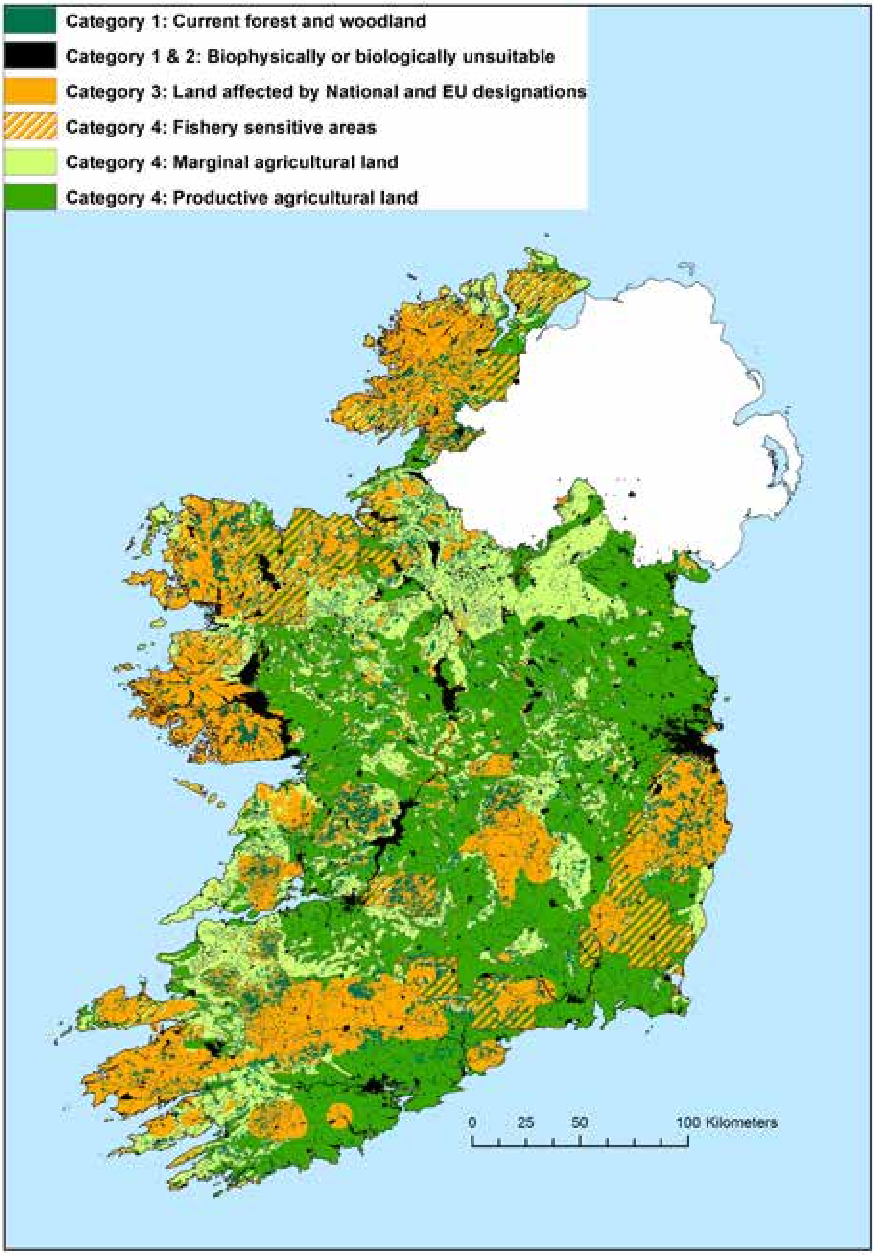

Figure 2: *Classification of Ireland's land area into four categories in relation to availability for forestry expansion and the area of productive and marginal agricultural land with most potentail for forestry expansion.*

also classified here owing to the resolution of datasets used in the analysis.

The area of marginal land with potential for afforestation covered 1.3 M ha. Grassland (dry/improved, reclaimed and wet) was the dominant land cover occupying 88% of the area (1.15 M ha). Farming enterprises were predominately cattle (49%) and sheep (27%) systems, with lower levels of dairy (18%), and mixed livestock (4%) systems (Figure 3). The proportion of land in tillage in this category was very low (2%) primarily because the land was either too wet or the terrain too steep to make this enterprise economic. Overall, the profitability of farming enterprises on marginal land was lower than on productive agricultural land with average farm income of

Table 4: *The area of land most likely to have potential for forestry expansion (category 4) in Ireland, classified as productive and marginal agricultural land, with associated land cover and soil characteristics.*

Land cover	**Productive agric. land** (ha)	**Marginal agric. land** (ha)	**Total area** (ha)
Tillage and grassland	2,217,782		2,217,782
Dry/improved grassland		804,836	804,836
Reclaimed grassland	118,299	186,500	304,799
Wet grassland	87,785	156,219	244,004
Cutover peat industrial	6,663	55,819	62,482
Shallow peat with shrub heath		42,602	42,602
Mineral Soils with shrub heath	13,589	21,489	35,078
Flushed blanket bog	2,055	28,236	30,292
Cutover peat other	199	1,955	2,154
Bare soil/peat	2,059	4,158	6,217
Unclassified	82	90	172
Other			
Total	2,448,513	1,301,905	3,750,419

Table 5: *The potential productivity (yield class) of land most likely to have potential for forestry expansion (category 4).*

Land cover category **Yield class range** **(m^3 ha^{-1} yr^{-1})**	**Moderate 14-18**	**Good 18-22**	**Very good 22-26**	**Excellent 26+**	**Total**
			Area (ha)		
Grassland	47,008	723,575	2,340,861	459,979	3,571,422
Other	104,600	37,534	27,119	9,745	178,996
Total	151,608	761,108	2,367,979	469,724	3,750,419

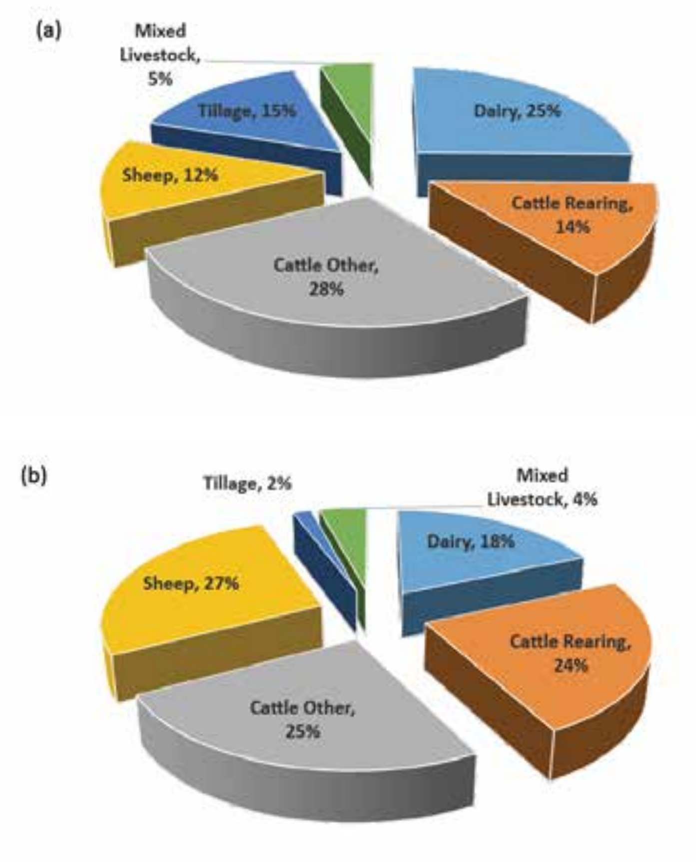

Figure 3: *The range of agricultural enterprises on (a) productive agricultural land and (b) marginal agricultural land. Note the decline in tillage and diary and increase in cattle and sheep enterprises on marginal land (data courtesy of National Farm Survey, Teagasc – Moran 2014).*

€17,006 per annum per household. A significant area of land thought to be unenclosed land (154,350 ha) was identified within this category, not likely to be the focus of future increased agricultural production or conservation objectives, being composed of cutover bogs, shallow peat/mineral soils with heath shrub vegetation, bogs with flushed vegetation, and bare soil/peat are deemed suitable for afforestation.

Historical planting in relation to land use

Over two thirds of all forests planted (532,000 ha) have been located on marginal agricultural land - a legacy of historical forest policy (Figure 4). The trend in recent afforestation (1989-2006) shows the same pattern, with 67% (122,345 ha) occurring on marginal agricultural land. Of marginal land planted, the area previously under grass represented 56% (68,426 ha). While lower levels of planting occurred on productive agricultural land during the period, the bulk (80%) of this planting occurred on grassland (49,520 ha), indicating the better quality of sites in this category. Indeed, the proportion of grassland being planted has increased year on year since 1989, reaching a maximum in 2000, only to decline in line with overall planting over the period 2000-2006. The average area of grassland planted was 6,000 ha per annum out of an average of 10,000 ha of the total afforestation per year in Ireland during the same period (Figure 5).

Limited afforestation has taken place in areas subject to national and EU designations and policies, comprising a total of 3,084 ha over the 5 year period 2007-2012 (source Forest Service DAFM). This is equivalent to 600 ha yr^{-1}. As these areas are subject to application of appropriate screening and certain qualifying criteria, this low figure is not unexpected. However given the area of lands classed in category 3 (Land affected by national and EU designations and policies) as being suitably productive (i.e. 0.897 million ha), the planting rates mentioned represent a very small area.

Discussion

The analysis presented has identified 3.75 M ha of land likely to have potential for afforestation. The bulk of this land, some 2.42 M ha, is productive agricultural land. Farming enterprises here are typically livestock based and show relatively good profit margins. It is likely that this land will be the focus of agricultural intensification and may see opportunities for farmers to change enterprises in line with demand for certain commodities (i.e. milk and grain). Agricultural output on this type of land is forecasted to increase in response to Food Harvest 2020 measures (DAFF 2010), perhaps leading to expansion in dairying, tillage and beef systems. Increased consolidation of agricultural holdings is also expected. There

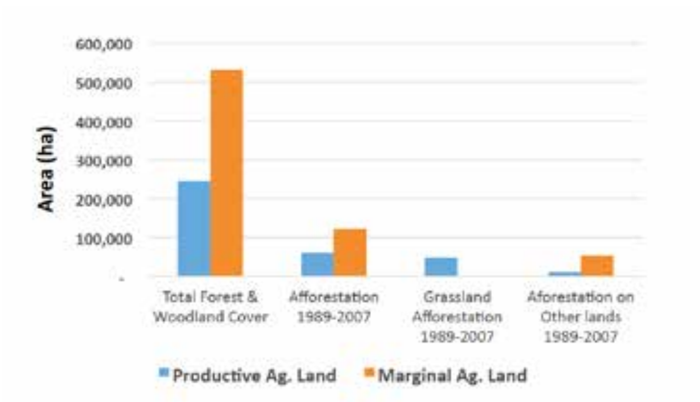

Figure 4: *The total forest and woodland cover in Ireland, planted on either marginal or productive agricultural land. Also shown is the area afforested from 1989-2007, together with the area of grassland and other lands afforested over the same period.*

will be limited opportunities for afforestation in these areas as the availability of this productive agricultural land is highly dependent on the performance of competing agricultural enterprises. It is likely that substantial increases in incentives would be necessary to encourage land-use change to forestry. Even with such incentives it is unclear whether this land would become available in significant quantity as other issues such as social circumstances, the perceived permanent nature of forestry establishment and devaluations in land price may ultimately limit uptake. In the short term, it may be possible to afforest those small areas of poorer soils occurring on the margins of productive land or where individual farming circumstances dictate.

There will be greater opportunities to establish forests on land classified as marginal or poorer quality or with a limited capability for agriculture. The results indicated good levels of potential forest production could be achieved on much of this land including the non-grassland areas. The returns from farming on this type of land have been much lower, as indicated by the Teagasc National Farm Survey data (Moran 2014). Typical farming enterprises carried out on marginal agricultural land include sheep and beef systems. These systems may be less profitable than other enterprises. Forestry may be a viable alternative on such land, particularly since wetter soils are more difficult to manage (Upton et al. 2013). Indeed, an analysis of traditional planting patterns confirms that these lands are more likely to be planted; the lower profitability associated with farming suggests that these lands should become more readily available for forestry. However, a significant proportion of this potentially available land was classified as grassland (1.146 M ha), of which 341,290 ha were probably limited to summer grazing with inherent problems of machine trafficability and animal poaching (wet and reclaimed grasslands) and higher management requirements, thereby rendering it more readily available for forestry. As considerable portions of this type have already been planted, the question of whether land in this category will remain more tightly held in agriculture remains to be seen. The key issue is whether lower quality grasslands can be utilised in more profitable livestock enterprises (e.g. dairying) following the removal of milk quotas in 2015. Availability for forestry may depend on whether these lands can be brought back into production through drainage and reclamation works at a reasonable cost. While it can be concluded that economics and land quality undoubtedly play a large part of the rationale behind land a change in land use, it is not the only factor that governs a farmer's choice of forestry as a land use option. The other issues that may influence the decision include the landowner's lifestyle choice, age and social circumstances (Ní Dhubháin et al. 1994, Duesberg et al. 2013) may ultimately constrain the availability of land for afforestation. These issues are beyond the scope of this paper.

The figures presented here show the challenge required to increase the forest area in Ireland, which might arise due to the over-dependence on land use change from agriculture to forestry. Therefore, it may be necessary to consider all potential sources including land that is not currently the focus of agricultural production. Thus, the 178,996 ha of unenclosed land that shows adequate levels of production potential should be considered. This may be easier to source for forest planting because of lower levels of farming activity and low profitability, so should be the focus of an overall plan aimed at achieving afforestation targets. Whether all or part of this area may be suitable for forestry could be assessed using further criteria or site classification methods to assist in quantifying their full potential (see Farrelly and Gallagher 2015 in this journal). It is reasonable to assume that afforestation of land affected by national and EU designations and policies will be limited in availability and will continue at the current modest rates (c. 600 ha yr^{-1}) or expand slightly into the future. However, given the scale of land classed as suitably productive, the planting rates mentioned here represents a very small area of the total. It may be necessary, therefore, to begin a new initiative to examine alternative models of afforestation (e.g. native woodlands), subject to specific requirements relating to conservation and carbon sequestration objectives, to assist in the achievement of targets.

Conclusion

The achievement of the forestry policy target of 1.25 M ha of forestry will be challenging, exceptionally so in the current time frame (2046) because of the situation regarding land availability. As productive agricultural land will continue

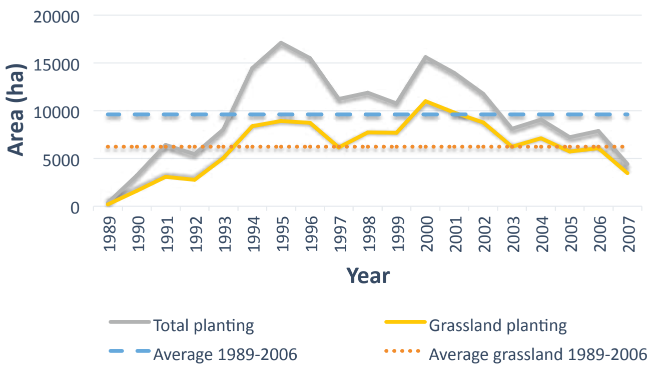

Figure 5: *Area of grassland (dry, wet and reclaimed) planted in relation to the total amount of forests planted over the period 1989-2006 –with the average area of grassland and total area planted for the same period.*

to be the focus of food production it may be prudent to focus on opportunities for afforestation on the 1.3 M ha of marginal agricultural. However the availability of wet and reclaimed grassland areas for forestry remains uncertain as these may become the focus of increased interest for agriculture if proposed new methods of management and drainage make such areas easier to manage. For many farmers on smaller holdings, forestry may represent an attractive potential alternative to unprofitable farming systems. However, despite having a significant proportion of marginal land, forest planting in certain counties is still relatively low (e.g. the northern counties of Cavan and Monaghan). Land that is considered of limited agricultural use may in fact be considered well suited to its current enterprise, so the availability of such land for conversion to forestry should not be automatically assumed. Efforts and incentives may need to be increased to encourage the conversion of more of this type of land to forestry. Given the significant area of productive unenclosed land, and its importance in the achievement of overall planting targets, its potential should be fully investigated.

Given the constraints on land use affecting its availability for afforestation, the impacts of other objectives inadvertently restricting land availability also need to be considered and evaluated. This work is the first detailed analysis of land availability for forestry in the last 25 years (since Bulfin's 1987 study), so it may be prudent, particularly in the context of target shortfall risk, to perform a bi-annual evaluation of land sources potentially available for forestry to take account of land becoming unavailable through planting or other land use designations, to monitor progress and to facilitate planning.

Finally the findings do point to a requirement for consideration of new initiatives, notably:

a) how the marginal areas in better farming regions might be brought into forestry and if compatible farm/forest systems could be developed;

b) mechanisms that might entice lower quality farmland, in areas traditionally with low afforestation rates, into afforestation;

c) new mechanisms for classifying and accessing suitable unenclosed land, including industrial cut over peat (e.g. Farrelly and Gallagher 2015 classification);

d) development of environmentally sustainable approaches for the establishment of forests on poor quality sites with low productivity potential;

e) mechanisms to encourage the implementation of alternative management objectives, such as carbon sequestration.

Acknowledgements

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Early-height variation between full-sibling families of Sitka spruce growing in Ireland

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Abstract: Progeny trials are an essential form of genetic testing required in every tree breeding programme. In Ireland, Sitka spruce (*Picea sitchensis* (Bong.) Carr) progeny created by controlled pollinations between 41 phenotypically superior parent trees have been planted in different full-sibling trials to evaluate the genetic value of family and parent material. Establishing full-sibling field trials is an expensive and labour intensive process and regular assessment of the progeny is required to evaluate the success of such trials. This study presents the first detailed examination of the Irish Sitka spruce full-sibling field trials, comprising 69 families measured after six to seven growing seasons. From the 69 families used, 25 were significantly taller compared to unimproved control material. For the most successful trial, a mean height gain of 10% was achieved by the improved material. Regression showed that height increment over a year was partly dependent on initial height at the beginning of the year, indicating that early selection of material might be an option. Additionally, one poorly performing female parent which produced generally low yielding progeny was identified. This parent should be removed from the breeding population to avoid future wasted investment and thus to save costs within the programme.

Keywords: *Tree breeding, early selection, progeny tests.*

Introduction

Sitka spruce (*Picea sitchensis* (Bong.) Carr) is the main commercially used tree species in Irish forestry, accounting for about 52% of the total forest estate (National Forest Inventory 2012, Farrelly et al. 2009). As with most other commercially used tree species, breeders focused heavily on improving productivity. Hence, since the early 1970s, a tree breeding programme has been established for Sitka spruce in Ireland using an initial selection of 747 superior phenotypes (plus-trees) based on several morphological characters (Thompson et al. 2013). Open-pollinated seed material from 505 of those plus-trees were collected and tested in replicated progeny trials across 41 locations in Ireland (Lee et al. 2013). Based on stem form and height of the progeny after six growing seasons (9 years from seed), a re-selection was conducted, which reduced the number of parental trees to 86. As earlier tests have shown a negative relationship ($r = -0.66$, Lee 2001, Wu et al. 2007) between 15-year stem diameter and wood density, wood density was also assessed. Forty-one plus trees with rapid growth rates that did not demonstrate a decrease in wood density were then chosen as the basis of the Irish breeding population, based on the performance of their half-sibling progeny.

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As during open-pollination any male tree can be the potential gene donor, progeny (half-siblings) can be very diverse in traits like height. To reduce the degree of this variation, specific crossing of superior parents (one male × one female) is used to create full-sibling families. Half- and full-sibling progeny were deployed in trials throughout Ireland to determine the levels of genetic gain that could be achieved. This process of progeny testing is essential for genetic testing but involves high costs for monitoring and maintenance (Lowe and Van Buijtenen 1989). The number of years progeny has to be monitored varies from species to species and is between six to 15 years for Sitka spruce in Ireland (Gill 1987, Thompson 2013).

Considering the time, labour and costs necessary for the progeny to be produced and tested with the objective of finding well performing families for future propagation, regular detailed examination of existing full-sib trials is of crucial importance. A preliminary evaluation of a six year old full-sib field trial that included 34 families of Sitka spruce plus trees showed that 18 were more than 15% taller than the commercially used Washington control material (unimproved), six were 10-14% taller and an additional five were 5-9% taller (Thompson 2013). However, NATFOREX (*Establishing a National Resource of Field Trials and a Database for Research and Demonstration,* Ireland) has made all data collected in these field trials available for more detailed analysis. In the current study, data from three field trials aged six to seven years with material derived from 69 full-sibling families were analyzed to determine the potential for improving the deployed Sitka spruce material in Ireland. Additionally, as one trial was measured for height in two consecutive years, a potential dependency of height increment on initial height was investigated. If such a relationship exists, it might be indicate a possibility to reduce selection age and thus decrease time and cost of producing improved material.

Materials and methods

Plant material

Forty-one superior parent trees selected during the Irish Sitka spruce breeding programme were employed in a controlled pollination programme leading to the production and harvesting of seeds from 69 full-sibling families. As seed availability was greatly dependent on flowering, not all seeds could be collected in the same year, which is why seed germination was conducted in a sequence of three successive years from 2005-2007 (11 families in 2005, 34 families in 2006 and 24 families in 2007). For each of the 69 families, 36 trees were grown in pots under greenhouse conditions for two years in Kilmacurragh, Co. Wicklow, until the material had reached a size of about 60 cm and was considered ready for field planting.

Field trials and experimental design

Three field trials were established in Ballynoe Forest located in south Ireland (52° 11' N, – 8° 30' E, 180 m a.s.l.). These sites were located close together on a moderately exposed gentle sloping afforestation site. The sites had a brown podzol soil and had been previously used for agricultural grazing. Long-term meteorological data (1981-2010, data collected by Met Éireann, Ireland) show a mean annual precipitation of 1,227 mm with the heaviest rain occurring in December and January (133.1 and 131.4 mm). Temperatures reach an average daily maximum of 18.7 °C in August and an average daily minimum of 8.2 °C in January with an annual mean daily maximum of 12.9 °C as well as an annual mean of 2,090 degree days (2007-2014).

The number of families planted in each site was determined by the amount of available seed material for the years 2005-2007, so 11 families were planted at site 1 in 2007, 34 families in 2008 at site 2 and 24 families at site 3 in 2009 (Table 1). Washington origin seedling material of the same age as the families was planted at each site as a control. This material represents seedlings that have not been through the improvement programme. Plants were arranged in a randomized block design with three (site 2 and 3) to four (site 1) replicate blocks per site, with each replicate block consisting of plots of 10 (site 1) or 12 (site 2 and 3) trees planted in a line at a 2 m spacing with one plot representing one family (see Table 1).

Measurements and data analysis

Tree height was measured at the end of 2011 for site 1. The trees on site 2 were measured in both 2011 and 2012, while those on site 3 were assessed only in 2012. One-way ANOVA was used to test for height differences between families where normality and homogeneity of variance was given. Fisher's Least Significant Differences (LSD) test was then performed to identity which families differed from each other. As the trees on site 2 were measured in two consecutive years, the potential impact of initial height on subsequent height growth could be assessed. Therefore, relationships for data from 2011 and 2012 for site 2 were assessed using linear regression analysis and relative height increment (RHI), the increase in height in 2011 from height in 2012 divided by the height in 2011.

Table 1: *Planting details for all sites.*

Site	No. of improved families	Planting date	No. of replicate blocks	No. of trees per plot	Measurement date	Age (years)
1	11	Mar. 2007	4	10	2011	7
2	34	Mar. 2008	3	12	2011 and 2012	6 and 7
3	24	Dec. 2008	3	12	2012	6

As during the production of the families used in this study certain trees were used multiple times as a male or a female parent, the contribution of specific parents towards a positive or negative influence on height performance was analysed. For this, we compared the height performance of families with a specific father or mother tree, used multiple times, with height performance of other families. All data analysis was carried out using the R statistical package (R Core Team 2013).

Results

General height performance

The size of the full-sibling families compared to Washington control material (WC) differed greatly for the three evaluated sites. For site 1, only one cross out of 11 was significantly taller than the control, having a mean height of 2.47 m (± 0.062 m) while WC was 9% smaller with 2.26 m (± 0.054 m) (P <0.001, Figure 1a). One cross was shown to be significantly smaller than WC at the end of the 7th growing season (2.09 m ± 0.068 m, P <0.001). Different results were found for site 2, where 34 families were present. In 2011, when trees were aged six years, 25 families were significantly taller compared to WC, with the tallest family 230 × 286 being 1.66 m (± 0.066 m, P < 0.001) compared to WC which was 32% smaller (1.26 m ± 0.06 m). From the nine remaining families, only 190 × 547 was found to be significantly smaller (1.07 ± 0.048 m, P < 0.001) than the WC. Similar results were found one year later (2012) on the same site, when the number of significantly taller families was reduced to 21, while just one significantly smaller family could be identified (190 × 547, P < 0.001, Figure 1b). The last site comprised of 24 families and showed similarities to site 1. Three families were found to be significantly taller, while two families showed a reduced height compared to WC (P < 0.0001, Figure 1c). On average, improved families were 10% taller compared to WC in 2012 at site 2 and less than 1% taller at sites 1 and 3. Overall, from 69 families used in this study 25 were significantly superior to the control (WC).

Parental contribution

As only site 2 was shown to have a substantial difference in height between WC and the improved families as well as between the improved families themselves, just this site was assessed for parental contribution. Parent 190 when used as a female parent produced four average or below average families compared to other combinations (Figure 2). One of the male parents combined with female 190, parent 547, yielded taller progeny when used in combination with 286, 500, 547 and 575. Male parent 286, for instance, was used nine times as a male parent and progeny reached heights from 1.93 m (± 0.067 m) to 2.14 m (± 0.079 m) except when combined with female 190, where an average height of 1.72 m (± 0.072 m) was observed. The two remaining male parents combined with female 190 showed similar results, producing smaller progeny than in other combinations. Even

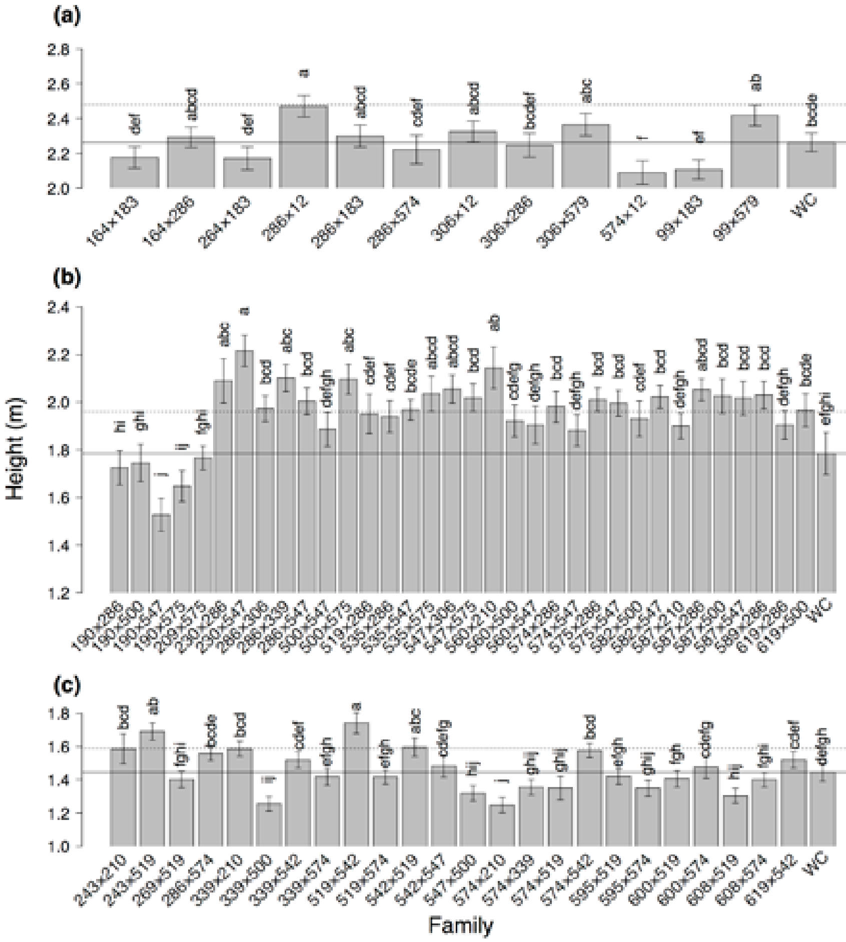

Figure 1: *Height performance of improved families and control at site 1 (a), site 2 (b) and site 3 (c). The graphs show means ± standard error of the mean. Means with the same letters are not significantly different. The solid line represents the average height of control (WC) and the dotted line shows a 10% improvement compared to WC.*

though male gene donors 286 and 547 were used 9 and 10 times to produce families, no specific influence on the height performance of the progeny could be found. Overall, female parent 190 could be identified to produce poorly performing progeny.

Height increment

Relative height increment (RHI) from 2011 to 2012 at site 2 was not significantly greater in any improved family compared to the control (Figure 3a). Three families (190 × 286, 209 × 575 and 230 × 286) were found to have a lower RHI ($P < 0.001$). Overall, height increment in 2012 was partly dependent on height in 2011 ($R^2 = 0.44$,

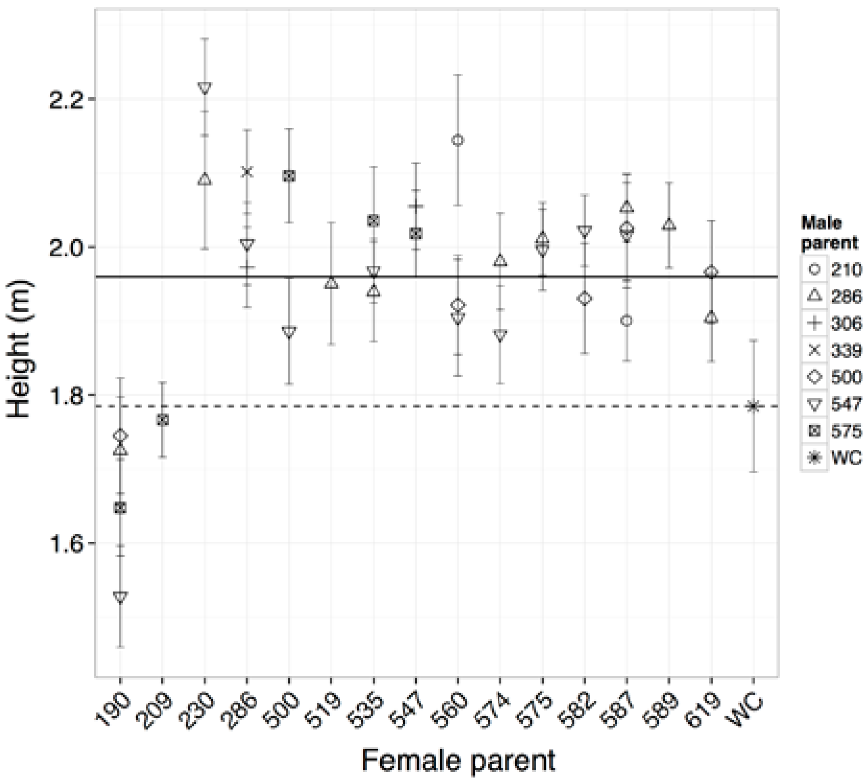

Figure 2: *Height performance of site 2 material in 2012, sorted by female parent. Data points show mean ± standard error of the mean. The dotted line shows the mean height of unimproved material (WC). The solid line represents the average height of all improved families.*

$P < 0.001$, Figure 3b).

Discussion

Height performance

Height differences between improved material and WC (Washington control) were present on all sites, but the number of taller families compared to WC varied greatly. Even though the difference in the number of taller families than WC per site is an important indicator of the parental selection success, finding even one superior family is an important outcome. After being shown to perform significantly better than WC, families can be recreated using controlled pollination and used for propagation and then deployed for commercial forestry. The degree of height differences is, to some extent, more important because only with a reasonable gain can commercial forestry profit from a breeding programme (Apiolaza and Greaves 2001). At site 1, the one taller family compared to WC showed an increased height of about 10% and could

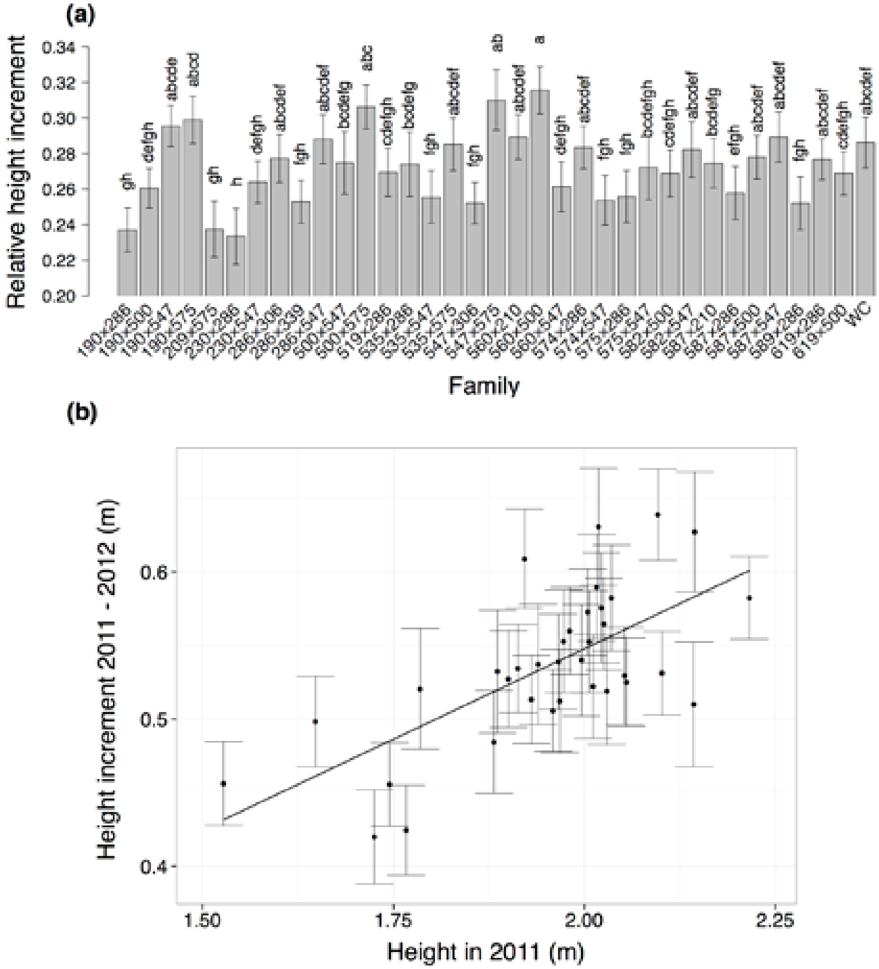

Figure 3: *(a) Relative height increment for site 2 between 2011 and 2012. The graph shows means ± standard error of the mean, means with different letters are significantly different. (b) Relationship between height increment and height in 2011 for site 2. Data points show means ± standard error of the mean. The solid line represents a linear regression.*

therefore be considered for inclusion in the vegetative propagation programme. However, the greater the number of superior families in a breeding programme, the higher the potential gain. At site 2, over 20 families were shown to be significantly taller than WC, reaching a height gain of over 24% for the best family. Across all families, site 2 showed an average gain of 10% in height.

Such a gain is similar or even higher than what has been achieved in other tree breeding programmes. In the USA, the *N.C. State University-Industry Cooperative Tree Improvement Program* (NCSU-ICTIP) has worked on the improvement of loblolly pine (*Pinus taeda* L.) since the late 1950s and has predicted height gains of about 6% to 10% after eight years of growth (Li, McKeand and Weir 1999). A gain in stem diameter of 15% to 18% at the end of rotation using full-sibling families was predicted in the breeding programme in Britain (Forestry Commission 2015). A recent review from Lee et al. (2013) showed that the use of cuttings from improved Sitka spruce could increase the genetic gain in height from about 15% to 20% in Ireland, but stated that data from Irish-based field trials are needed to confirm this. The results in this study agree with this estimate, being a first and promising full-sibling analysis. It is important to note that the sites analysed in this study were not replicated over different climatic conditions within Ireland, resulting in the possibility of measured gain being over or underestimated due to a missing calculation of genotype by environment interaction. The same missing genotype by environment interaction assessment has given reason not to calculate heritability estimates, a value expressing the degree of this interaction. A high heritability would indicate that crossing certain plus-trees with high yielding progeny would consistently produce good performing progeny, independent of the planting location. As the material used in this study was not replicated, a measure of heritability would just be meaningful for this location only. Additionally, to achieve a complete assessment of the sites, more traits need to be measured (for example stem form and wood quality).

Based on the results of this study, some families derived from the parents currently used in the breeding programme can be used to increase the gain of Sitka spruce used in afforestation. However, it is important to note that while all full-sibling families are progeny of improved material, less than half showed a significant improvement over the control. This is a concern with respect to the current available "improved" material. Additionally, while Thompson (2013) pointed out that 29 out of 34 improved families at site 2 had at least 5% greater average heights compared to WC in 2011, it was found that for four of these families the difference was not significant. Moreover, over only one year, the number of improved families that were significantly taller than the control fell from 25 to 21. The trees are, however, still young and could potentially change their growth patterns at an older age.

It is also important to note that, even though site 1 and 2 were the same age at the time of measurement (seven years), site 1 progeny performs generally better than site 2. This includes WC, which was 27% taller at site 1 compared to site 2. As these sites were planted and measured in different years, it might be argued that the plants were exposed to different weather conditions, leading to different growth characteristics. However, as detailed growth data for the sites are not available, this theory could not be verified.

Height increment and parental contribution

To ensure that parents used in breeding programmes are of high genetic quality, progeny of the parent trees must be assessed to either keep or remove certain trees from the breeding programme (Thompson 2013, Hallingbäck and Jansson 2013, Lowe and Van Buijtenen 1989). To detect parents with low genetic value based on progeny performance in a breeding programme, they must be used multiple times as a either male or female parent within a progeny trial. Only then is it possible to differentiate between generally bad combiners, which always produce poorly performing progeny and specifically bad or good combiners. Depending on seed production when creating full-sibling families, such an assessment of the progeny is not always possible if each parent is not involved in a number of full-sibling families as either a male or female which makes it difficult to remove badly performing parents from the programme.

In this study, female parent 190 was identified as being of low genetic value, as independent of the male parent, tree heights were generally lower compared to all other families. This information can be of use for the Irish Sitka spruce breeding programme as with the removal of mother tree 190 from the programme resources used for progeny testing or propagation could be saved. Ideally, trials need to be conducted with a wider range of male parents crossed with one female parent and *vice versa*. For example, female parent 230 produced two tall families (site 2), but more crosses with this parent are needed to confirm its genetic worth.

At the age six to seven years at site 2, no family had a significantly higher or lower relative growth rate compared to WC. Considering that 21 families after seven years of growth were significantly taller than WC, this could indicate that families establish their superiority during the early years, i.e. due to higher juvenile growth rates. This assumption is supported by the strongly significant regression between 2012 height increment and height at the end of 2011, indicating that taller families keep getting taller (Figure 3b). It would be of interest to validate this pattern over more years of growth.

Currently, it can take up to 15 years until progeny is assessed for parental selection (Gill 1987, Thompson 2013). This time period is nowadays used in the commercial programme due to concerns that additive variance (and thus heritability) declines with age. However, Gill (1987) found a strong correlation between three-year height and 27-year stem diameter in Sitka spruce and concluded that a reliable height assessment could be carried out at the age of five years. Height measured as early as three years also has been found to correlate strongly with height of older trees (Gill 1987). As rapid juvenile growth rates may be negatively correlated with wood density, height alone should not be used to assess progeny performance. Lee (1997) showed that juvenile wood density at the age of 9 years is a sufficient indicator of mature wood density.

Most studies have focused on half-sibling families. Full-sibling families are expected to show lower within-family variation since all siblings have the same two parents.

Therefore it is of value to investigate traits such as vigour and wood density at an early age in full-sibling field trials. Early selection can, if juvenile-mature correlations are significant, greatly benefit a breeding programme due to a drastic reduction in time, cost and labour spend on progeny trials. The results shown in this study indicate that superiority could be established earlier than seven years, implying the possibility of selecting full-sibling progeny early, which would greatly improve the Irish Sitka spruce breeding programme. However, more research is needed to quantify growth of full-sibling families over more years to support this theory.

Conclusion

This study represents the first detailed examination of full-sibling field trials as part of the Irish Sitka spruce breeding programme. After analysing data from three sites with a total number of 69 families, it can be concluded that most combinations of improved parents resulted in tree height either greater than or equal to that of unimproved material. One family was 24% taller than the control. Within a trial, families with one parent in common can behave quite differently. One particular female parent consistently led to below-average height of the progeny. Additionally, results showed a consistent ranking of families over 2 years of growth.

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Factors affecting the economic assessment of continuous cover forestry compared with rotation based management

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Abstract

Economic comparisons between Continuous Cover Forestry and rotation-based forestry are complex and often inconclusive as there are fundamental difficulties in comparing even-aged and uneven-aged management systems from an economic point of view. These difficulties are multifactorial but they can be broadly grouped into methodological factors and management related factors. This paper explores some of the most influential issues affecting outcomes in economic valuations and in particular how they affect CCF compared with rotation based management. The discussion of these issues will help to inform the debate on CCF and its applicability to forest owners more familiar with rotation based forestry.

Keywords: *Valuation method, discount rate, timeframes, risk, management factors.*

Introduction

One of the most common questions that arises when discussing Continuous Cover Forestry (CCF) (often described as uneven-aged forestry) as a forest management option, particularly in countries where even-aged forestry is the norm, is how does CCF compare economically with rotation based management, such as conventional clear felling systems? Economic comparisons between these two approaches have previously been made. In a review of such studies, Hanewinkel (2002) attempted to interpret these comparisons using a model study but concluded that there are fundamental difficulties in comparing even-aged and uneven-aged management systems from an economic point of view and that it seems most unlikely that even technical improvements of model studies or new empirical studies with a broader data base could lead to improvements in such comparative economic studies. The reasons for this are multifactorial and depending on the valuation method used, not all factors are or can be included and "like" cannot be compared with "like". This paper aims to consider some of the issues that most heavily affect outcomes in economic valuations and in particular, how they affect CCF compared with rotation based management. These issues can be broadly grouped into methodological factors and management related factors and these are addressed below.

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Methodological factors

Valuation method

A commonly used valuation method in even-aged forestry is *Net Present Value* (NPV) where future cash flows associated with the remainder of the rotation are discounted back to the present using a discount rate (Little et al. 2013). This type of valuation method is not suitable for uneven-aged forestry where there is no defined rotation and where the capital value of the forest is never liquidated and does not appear in the cash flow. Instead, the two main valuation methods associated with CCF (as cited in Süsse et al. 2011) include:

- Potential Value (PV). This was calculated by Süsse et al. (2011) by dividing the annual yield by a discount rate:

  PV = Annual Yield (€) / Discount Rate

  Such a valuation method is clearly unsuitable for rotation based forestry where the yield comes predominantly in a single year. However, this method is considered ideally suited to valuation in CCF stands as there is no requirement to predetermine the harvesting date of all or any trees. Instead it allows for the valuation to reflect the future optimal timing of harvesting of individual stems as determined by the manager. The Association Futaie Irréguliére (AFI), an association of forest owners and foresters originating in France, uses potential value as the basis of a performance management indicator for stands in its network (Vítková et al., 2013).

- Standing Value (SV). The current standing value of all timber, if realised (this is also known as the capital value) (Süsse et al. 2011). This clearly would not be useful in describing young or semi-mature even-aged forests as the future value, when mature, is not accounted for. Nor is it entirely suitable for valuing a forest in transition from even-aged to uneven-aged as in such a scenario, investment in forest management may not yet have resulted in the forest composition or structure ultimately sought.

Choosing a valuation method that suits both even-aged and uneven-aged forestry is therefore challenging and any comparison between forest management types must discuss the influence the valuation method has on the outcome.

Discount rate

Future cash flows associated with future forest management can only be compared if adjusted to a common year and this is done using a discount rate. Little et al. (2013) stated that forest valuations are extremely sensitive to the discount rate used due to the length of time between planting and final harvest which can vary from 30 years for conifers to over 100 years for some broadleaf species such as oak. This obviously assumes a rotation based system of management. The choice of discount rate can significantly increase or decrease the valuation as well as determine the viability of a forest investment. To illustrate this point, Tahvonen (2011) attempted to compare uneven-aged and even-aged management systems in Norway spruce in Nordic countries and concluded that either system could be declared more economically favourable depending on growth rate and interest rates used. In general terms, a high discount rate favours short term projects, while a low discount rate favours longer term projects (Price, 2011; Little et al., 2013). Davies and Kerr (2011) use a declining discount rate in their analysis of costs and revenues of transformation to CCF. This is as recommended in the British Treasury *Green Book* (H.M. Treasury, 2003) which specifies that a declining rate is appropriate when considering long-term investments. The rates used range from 3.5% for the 0-30 year period reducing to 1% for the period beyond 300 years. Price (2011) examined the impact of declining discount rates and their applicability to forestry in some detail and discussed how they affected optimal rotation lengths depending on the nature, consistency and predictability of future forest management decisions. The question as to what is an appropriate discount rate is intimately connected with the time preference of the decision maker, the valuation timeframe and the treatment of risk. The influence of timeframe and treatment of risk are discussed separately below.

<u>Timeframes</u>

The timeframe or management period over which a forestry investment is valued has a significant bearing on the outcome. Typically, the economics of an even-aged forest management system are assessed for the duration of a single rotation and the residual land value following clearfelling is normally included in the analysis (Little et al., 2013). This rotation period is dependent primarily on species and site productivity and can range in Ireland from 30 years for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) to over 100 years for oak (*Quercus* spp.). The start point for such an analysis can be at any point in the rotation and the timeframe is simply the remaining management period up to and including clearfelling.

The timeframe for the economic assessment of CCF cannot be defined so simply or in the same way. The start and end points for such an analysis also have a significant bearing on the outcome. Davies and Kerr (2011) discussed how the choice of start point and the choice of length of a finite period for comparing cash flows are arbitrary and the effect of excluding cash flows beyond the time horizon must be considered when interpreting results. Considerations with regard to the start point and analysis period include:

- whether the forest is already in a "Steady State" and the management is focused primarily on the harvesting of increment (Hanewinkel 2002);
- whether the forest is currently even-aged but about to be transformed over an undefined period to an uneven-aged forest (Davies and Kerr 2011);

- whether the forest is undergoing transformation from an even-aged to uneven-aged status and at what stage in this process the forest is currently at.

The analysis period for all scenarios must obviously have start and end points. If the objective is to compare even-aged and uneven-aged forest management systems, it is difficult to define a common period which best reflects the particular characteristics of each system. A long period in which a "steady state" of CCF management is achieved would need to be matched by multiple even-aged rotations. A shorter period, for example, corresponding to one even-aged rotation, would need to include a capital value for the retained forest stand under CCF management. In their analysis of costs and revenues of transformation to CCF, Davies and Kerr (2011) examined three different timeframes, (20 years, 100 years and perpetuity) when comparing a rotation based management system with three different CCF scenarios. They found that each timeframe produced different results in terms of the relative economic ranking of each scenario. A similar study in Germany by Knoke and Plusczyk (2001) based the timeframe around the expected transformation period from even-aged to uneven-aged forestry (60 years) and added this to a 17-year lead-in period for which good baseline data were available. The theoretical analysis compared the 77-year period up until the stand was considered transformed with a similar period under even-aged management involving 57 years until clearfell and a further 20 years post clearfell of the restocked stand. The economic analysis showed a considerably lower amount of harvested timber and a considerably lower income earned for the transformation strategy compared with the even-aged management system. However, income from the transformation strategy occurred earlier and was more uniformly distributed over time. Due to this fact, the net present value (NPV) of transformation exceeded that of even-aged management during the 77-year period, given an interest rate of 2.6%.

<u>Market factors</u>

In general terms, forests managed under CCF will produce logs of larger dimension than those managed under a rotation based system (Hanewinkel 2002). This is because, particularly during a transformation period, individual trees are retained in the stand as seed producers and to provide shelter for a longer period. These retained stems are generally of higher than average quality as:

- they are selected as showing desirable traits as potential seed-producing trees;
- they are selected as trees which will result in greater value increment if retained, relative to other stems that may be selected for felling.

Common questions that arise for practitioners in CCF are whether or not it is possible to sell logs of larger dimension and, if so, whether or not a premium price is paid for large quality logs (Price and Price 2006, Süsse et al. 2011). This depends on both species and local industry conditions. While rotation based forest management generally references a single price/ size curve for the species and market in question, the mixed species and the increased focus on quality associated with CCF management means that a number of different price / size curves may come into play. For example, Douglas fir (*Pseudotsuga menziessi* (Mirb.) Franco) and Sitka spruce, often used in mixture in CCF management have two different price / size curves (Poore 2014). Similarly, high and low quality broadleaves have entirely different price / size curves.

Because there are few published price / size curves for minor species or that account for the more sophisticated grading associated with species that produce higher value assortments depending on quality, most comparisons between even and uneven-aged forestry rely on standard price / size curves and commodity prices. In the eyes of CCF proponents, this results in an undervaluing of the economic returns available (Poore 2007) while in the eyes of proponents of rotation based forestry, the lack of concrete data for larger and supposedly higher grade timber achieved at local log auctions reflects the uncertainty associated with CCF (Price and Price 2006). Poore (2007) argued that CCF management allows for the felling of individual trees at their optimal size which he defines as the point where the expectation or potential value equals the standing value. This can be translated into what is commonly called a "Target Diameter" by CCF foresters and this varies with species, market conditions and quality. However, the only published analyses in which reliable timber prices for such categories can be used are retrospective and case studies of such management are currently the best way of exploring the economic performance of CCF relative to conventional management.

Davies and Kerr (2011) found, regardless of the fact that log sales are the only income source for their analysis, that in a sensitivity analysis, different product prices investigated did not alter the relative ranking of management scenarios by NPV. In a study of the economics of transforming Norway spruce (*Picea abies* (L.) H.Karst.) from a regular (even-aged) to irregular aged stand structure (considered synonymous with CCF by Helliwell and Wilson 2012) in Upper Bavaria (Germany), Knoke and Plusczyk (2001) also found similarly that log prices had a minimal effect on relative economic comparisons and that the most influential factor in such comparisons was the interest rate used.

While changes in timber prices may have little relative influence on the outcome of comparisons between silvicultural systems, they are significant when considering risk and strategies for mitigating these (Knoke et al. 2001). In general terms, more developed forest industries, where there is a long tradition of timber production and processing, will have more developed markets for niche products and in particular for quality timber grades. This is evidenced in central Europe by the existence of premium log auctions. At these events, premium logs across a range of conifer and broadleaved species are withheld from the general commodity markets and separately auctioned and sold into niche markets such as veneer, bespoke furniture etc.

Treatment of risk

The treatment of risk is an important consideration in any economic analysis of forestry and when different silvicultural management options are compared, unequal risks should be taken into account. In Ireland, Little et al. (2013) classified risks to forestry as either nature based (e.g. fire, wind, flooding etc.) or market based (e.g. changes in supply/ demand ratios for certain product assortments, fluctuating exchange rates in export markets etc.). While this classification is useful, the manner in which such risks are quantified economically is a subject of considerable debate in international literature. Forest management systems and practice can be used to mitigate against some risks and this is particularly pertinent in relation to CCF management. Proponents of certain silvicultural systems will often cite risk reduction as a reason for practising such a system. For example, the Northern Ireland Forest Service operates a “no-thin” policy for most forests to reduce the risk of windthrow (Phillips 1980). Conversely, Vítková and Ní Dhubháin (2013) point out that throughout Europe, forest authorities are choosing to transform stands in the belief that CCF will lead to greater stability and that a key driver for this policy was the high levels of windthrow experienced as a result of major storms in the 1980’s and 1990’s.

Knoke et al. (2005) developed a “hazard rate” per decade of age for spruce and beech (*Fagus* spp.) which demonstrated how risk of loss to natural hazards increases over time for both species. The increased risk of retaining older or larger trees has clearly to be balanced against their increasing value. Knoke et al. (2005) also analysed how varying the percentage of each species in mixture with each other affected the overall risk (nature and market based combined). They found that there were strong economic advantages for the ecological concept of mixed forests. Despite lower productivity in beech compared with spruce, a mixture of 30% beech would still result in 97% of the maximum economic utility of the site because of its role in reducing ecological and market based risk. In other words, they concluded, natural diversity can render economic advantages.

The concept of mixed species and mixed aged forests being more resilient in terms of ecological or natural hazards is commonly discussed internationally. In Lower Saxony, Germany, the state government set up the LÖWE (Lanfristige Ökologische Waldentwicklung) Programme in 1991 whereby all state forests would be managed using 13 guiding principles associated with close to nature forest management/ CCF. This policy states that “silviculture in the state forests is to realise and maintain the (forest structure) types that are more varied and that pose fewer risks. These are vertically graduated stands with as much variation as possible in small areas". This policy has resulted in a reduction in the requirement to restock following clearfell, storms or fire from almost 80% to less than 5% over a 30-year period (Lower Saxony State Forest 2011). Similarly in Slovenia, where close to nature forestry has been formally used for over 50 years, the Slovenian Forest Service have identified this type of management as central to optimising resistance of forests against insect and disease outbreaks, storm damage and fires (Slovenian Forest Service 2008).

The risk mitigating features of CCF as experienced by Lower Saxony and Slovenia, for example, are not in question. Knoke (2012) cited a number of empirical and theoretical studies that all agree with the hypothesis that CCF results in more resilient stands and reduced risk from natural hazards. However, there is a question regarding the resilience of forests while undergoing the transformation process from even-aged monocultures to mixed age and species forests. This question is raised by Knoke and Plusczyk (2001) who point out how the resilience of stands in transformation to CCF is different on wet sites vulnerable to windblow (e.g. in Scotland) than on drier, stable sites (e.g. in Bavaria). The risk of windblow during and particularly in the early stages of, the transformation period is recognised by CCF practitioners in the United Kingdom and Ireland and early thinning interventions and irregular thinning patterns are recommended by both Otto (2002) and Morgan (2006) as mitigation. The question of site suitability for CCF is also addressed by Mason and Kerr (2004) who list stability as a selection criterion when identifying sites suitable for transformation from even-aged spruce plantations to CCF.

Knoke (2012) pointed out another risk-reducing feature of CCF management associated with the spread over time of timber sales, used to reduce the risk of exposure to cyclical or sudden fluctuations in timber prices. Rotation based forestry, in which most of the produced timber is sold over a very short timeframe, can be exposed to such fluctuations. However, on stable sites, the timing of all harvesting operations, whether CCF or rotation based, can be optimised to avail of peaks in timber price cycles.

<u>Treatment of non-timber values</u>

Most economic analyses of both even-aged and uneven-aged forestry do not take account of non-timber values such as income from recreational activity, carbon storage, ecosystem services etc. While there is little empirical evidence in the literature to suggest that either forest management system delivers such services more effectively than the other, most commentators accept that the value of such services are higher with CCF management than rotation based forestry (Price Undated, Vitkova and Ní Dhubháin 2013). In an analysis of the benefits and profits of single tree selection silviculture in the Ozark region of Missouri, USA, Hamatani and Goslee (2008) concluded that, without valuing ecosystem services, single tree selection is profitable for landowners and may even compete financially with even-aged management. While the focus of their analysis was on the economic aspects of uneven-aged management, they suggested that there were numerous ecological factors that should be considered for a complete comparison with even-aged management.

Taxation policy

The way in which taxation policy in different jurisdictions is applied to income from timber sales has implications with regard to the forest management system employed by forest owners. In situations where income from timber sales is not taxable then there is obviously no influence in this regard. However, in situations where progressive tax rates apply to timber income whereby the tax rate increases with increasing income, there is a strong incentive to maintain a smooth, regular income stream associated with CCF as opposed to once-off large income events associated with clearfelling. In Ireland, income from the occupation of woodland (which includes timber sales) of up to €80,000 per annum is exempt from income tax. This is equivalent to approximately 4 ha of a clearfell. Given that the average private forest is 9.1 ha (DAFM 2014), this taxation policy is likely to result in the staggering of clearfell operations on any single property and therefore a significant restructuring of existing private forests. Some forest owners are likely to go further and seek to regularise the income production from their forest through the transformation to CCF. In other jurisdictions such as France where a land tax is levied, this applies equally across all forest management types (Süsse et al. 2011) but regular income from CCF management may be more convenient to owners in discharging this tax.

Growth and yield models

The lack of stand based growth and yield models for CCF causes difficulties for researchers, practitioners and land owners in making comparisons with even-aged forestry for which such models are readily available. This is going to remain an ongoing issue as it is unlikely that reliable CCF models will be available to foresters for the foreseeable future. Such models would be considerably more complex to produce than even-aged forestry models and this is a further impediment to any short to medium term prospects of them becoming available. Single tree models have the potential to be used in forecasting future growth and yield of individual stems. However, most successful CCF management is very dependent on the qualitative selection of stems for both retention and felling made by the forest manager and single tree models are generally only quantitative and cannot reflect the important qualitative issues which arise when deciding which trees to retain and which to fell. The spatial and structural diversity and the stability of the stand are all affected by the qualitative marking decision of the manager (Vítková 2014). The mathematical models can aid foresters in making quantitative decisions only, thus reducing their reliability. In the absence of reliable growth and yield models, practitioners must interpret empirical and theoretical studies and apply them as best they can to their own forests. For most practitioners, referenced and observed case studies are probably the most useful resources to assist decision making with regard to future forest management choices. While there is a danger that "best practice" case studies may not be representative, they do act as useful indicators of the potential of different systems.

Management related factors

Natural regeneration, subsequent re-spacing and tending

Regeneration of a forest can be achieved artificially through planting as is typically the case in the clearfell system, or through natural regeneration which is generally associated with shelterwood systems and CCF. The cost of re-establishing a forest post clearfell will vary depending on the site productivity, species selection, the owners' objectives and on the amount of money to be invested to achieve a desired economic return on the investment. Reforestation costs, including ground cultivation, planting costs and maintenance of the young trees to keep them free from vegetation and weevil attack until successfully established, are generally higher than afforestation costs. On low productivity sites these costs can often make the management of the forest uneconomic. On such sites, Yorke (1998) considered CCF to be desirable.

Natural regeneration is one of the key elements influencing the outcomes of financial comparisons of clearfell systems with shelterwood or uneven-aged forests. Davies and Kerr (2011) noted that the costs of natural regeneration (even including the costs of respacing) were lower than those of artificial regeneration. In their economic analysis of three CCF transformation scenarios and one clearfell and replant scenario, the transformation to a simple structure produced the highest NPV in perpetuity, a finding they attributed in part to the avoidance of replanting costs through the use of natural regeneration. However, it is wrong to assume that natural regeneration always has a positive effect on the economics of forest management. Depending on the density of the natural regeneration, the cost of tending operations and pre-commercial thinnings may have to be factored into any investment appraisal to reduce stem numbers to desired stocking levels prior to thinning. Dense natural regeneration, that can exceed 100,000 seedlings per hectare, has become increasingly common on recently clearfelled stands and stands managed as CCF in British uplands (Mason 2010). Even though there will be natural self-thinning through intense competition, respacing costs of up to £1,000 ha^{-1} (€1,400 ha^{-1} in August 2015) (Mason, 2010) may need to be incurred to ensure the future economic development of the stand. Such costs can arise in un-controlled situations and they serve to illustrate the importance of good management decisions in the transformation period to ensure that desired stocking levels are not dramatically exceeded. Even in situations where stocking levels achieved through natural regeneration are appropriate, it may still be necessary to incur the cost of enrichment planting whereby additional or compatible species for future CCF management which are currently absent from the site are purchased, planted and subsequently maintained.

Roads, racks and infrastructure

Road densities vary in stands managed under the clearfell system. In Ireland the standard road density for harvesting roads is considered to be 20 m ha^{-1} (Forest Service 2012) and this is the maximum level for which funding is available under the Forest Service's Road Grant Scheme (Forest Service 2012). With modern machine-based harvesting infrastructure, forwarding distances of up to 300 m allow for lower road densities to serve the forest. In general terms, the further the forwarding distance the higher the harvesting cost. In every forest property there is an optimal roading density that is a trade-off between the increased harvesting cost associated with less roading and the capital cost of developing road infrastructure (Ryan et al. 2004). This optimal roading density is also influenced by the timing, frequency and intensity of thinning operations and the capital cost of road development is more justified where there are regular thinnings planned than in a forest where no thinning is planned. For this reason, it could be claimed that CCF management requires more roading than conventional clearfell management. However, de Turckheim (1993) noted that the costs involved in the maintenance of roads and the infrastructure in CCF forests were similar to those of rotation based forest management. Knoke et al. (2001) also found that road costs were similar in transformation to CCF and in a clearfell system although it is unclear whether they are referring to capital or maintenance costs. Davies and Kerr (2011) also assumed no cost differential for roading maintenance between the four scenarios they compared. However, they qualified their assumption indicating that it applied to sites where conditions were considered to be highly suitable for machine access and where minimal remedial works were required for forest roads after harvesting.

In a clearfell system, extraction racks are laid out at first thinning stage and these racks serve all future thinning operations. These racks are generally spaced approximately 12 to 14 m apart depending on the initial cultivation method. During the clearfell operation, no consideration is taken of where extraction previously took place as forwarding of timber to the forest roadside is on large brash mats formed from the brash residue from the clearfell. In a CCF system a permanent network of 4 m wide racks at 20 to 40 m spacing is required (Süsse et al. 2011), although closer rack spacing is being used in Britain and Ireland during the transformation stages. The permanency of these racks is extremely important as harvesting machinery is restricted to travelling on the racks only, leaving the forest soil between racks free from risk of damage or compaction. The concentration of machinery on these racks on wet or vulnerable soil types can potentially lead to rutting and, given the need for a permanent infrastructure in CCF, some rack development, strengthening and maintenance work will often be required at an additional cost that is not likely to be incurred in the clearfell system. On such site types, Graduated Density Thinning (GDT) as devised by Tallis Kalinars (cited by Vitkova and Ní Dhubháin 2013) has been used by some practitioners. In this system, both the first and second thinning will have sufficient brash matting for heavy forest machinery with subsequent selection of permanent machine racks and abandonment of other redundant racks from third thinning onwards.

Harvesting

If one assumes a mechanised approach to harvesting using modern harvesters and forwarders, the primary factors that dictate costs in timber harvesting are tree size (the smaller the tree size, the higher the cost) and forwarding distance to roadside (the longer the forwarding distance the higher the cost), regardless of silvicultural system. For even-aged plantations, the harvesting cost at 1st thinning therefore does not differ significantly between conventional management and the initial intervention in transforming to CCF (Davies and Kerr 2011). This is because a high percentage of the thinning volume is systematic in the form of lines of trees removed to create thinning racks rather than selective thinning. However, when the early stages of transformation to CCF are compared, i.e. 1st, 2nd and early subsequent thinnings with similar thinnings in conventional management it is reasonable to expect lower costs and greater revenues from CCF due to a higher average tree size and potentially a higher overall harvest volume. Davies and Kerr (2011) stated that transformation to CCF is less costly than current conventional management over a 20-year period because of high initial thinning returns. Vítková (2014) noted that thinning used in the transformation process to CCF will have to be heavier in intensity and commence earlier than in comparable even-aged clearfell / replant management. The resulting earlier and larger revenues skew the financial advantages in favour of the transformation process, especially when high discount rates are used (Knoke and Plusczyk 2001). Results from a thinning trial described by Vítková (2014) show greater volumes per hectare and greater average tree sizes removed for both crown thinning and GDT (both associated with transformation to CCF) at first and second thinning stages compared to conventional low thinning (Table 1).

Table 1: *Out-turn of volume, basal area, mean DBH and average tree size removed in first and second thinnings in trials in Ballycullen, Co. Wicklow and Fossy Hill, Co. Laois.*

	1st Thin				2nd Thin	
Thin type	**Basal area removed** (m^2 ha^{-1})	**Volume removed** (m^3 ha^{-1})	**Mean DBH removed** (cm)	**Average tree size removed** (m^3 $tree^{-1}$)	**Average tree size removed** (m^3 $tree^{-1}$)	**Mean DBH removed** (cm)
Low (Clearfell)	13	59	14	0.078	0.116	16
Crown (CCF)	14	66	16	0.105	0.164	18
GDT (CCF)	15	64	15	0.088	0.145	17

Source: Vítková (2014).

Similar trends were noted in an initial crown thinning operation carried out on AFI sites[1] with what would be forecast for those sites under conventional management (Vítková 2014).

In the latter half of the transformation period and in the "steady state" period, harvesting in CCF systems generally concentrates on the removal of larger trees (Hanewinkel 2002), leaving smaller trees to develop further. This results in a higher percentage of high value assortments and therefore a higher value per m^3 of timber harvested. Davies and Kerr (2011), referencing a number of other studies, show clearly that both harvester and forwarder productivity increases with average tree size. However, there is no consensus in the literature on this. Andreassen and Øyen (2002) compared harvesting costs in Norway spruce between a clearfell system (€14 m^{-3}), a group system (€16 m^{-3}) and a selection system (€15 m^{-3}). In this case, despite the average tree size being higher in the selection (CCF) system, the authors claim the increased harvesting cost is due to a greater distance between the harvested trees and restricted space for harvesting and forwarding between the retained trees. The potential for damage to naturally regenerating, pole stage and other retained trees during harvest operations in CCF systems is a common point of discussion amongst foresters. Davies and Kerr (2011) do refer to increased costs that will be incurred as a result of having to use skilled motor manual (directional) felling to avoid such damage and also because tree sizes become too large for harvesting machinery to control. De Turckheim (1993) stated that harvesting costs in CCF are slightly higher for trees of comparable size because of the need to protect young seedlings and poles.

[1] An AFI (Association Futaie Irréguliére) site is a working research stand where the AFI Inventory Protocol (Susse et al. 2011) is in place and the forest is managed as Continuous Cover Forestry.

Price and Price (2006) addressed the question of thinning by removal of larger than average sized stems, referred to by them as "creaming". They concluded that this might be a financially attractive transformation route, yielding larger immediate revenues but it also results in greater openings in the canopy for natural regeneration than low thinning or conventional crown thinning.

Management costs

Süsse et al. (2011) commented that there is no particular distinction regarding overheads in CCF. However, they also accepted that the lack of clear management models, the need for a flexible approach to management and the potential for complex management decisions can lead to increased management costs. They reported that across the AFI network, CCF management costs range from €10 to €30 ha^{-1} yr^{-1}. This does not include the production of management plans, costed at €1.50 to €2.50 ha^{-1} yr^{-1} or the important cost of marking which averages €12 ha^{-1} yr^{-1} and ranges from €5 to €35 ha^{-1} yr^{-1}. This would give a total CCF management cost (across all AFI stands) of between €16.50 and €67.50 ha^{-1} yr^{-1}. Davies and Kerr (2011) failed to find a consistent pattern for the costs associated with CCF compared with conventional management systems, stating that published figures give little indication of what the range of management costs might be. They arrived at a cost of £30.27 ha^{-1} yr^{-1} (approx. €42.34 in August 2015) for conventional forest management operations and estimated that transformation to a simple structure will incur a 150% cost increase and a transformation to a complex structure will result in a 200% increase, due to increased demands for planning, supervision and training for staff who are unfamiliar with CCF. They also noted that even if these relative costs are realistic the differences will decline over time as experience of CCF systems increases.

Conclusion

Direct economic comparisons between rotation based management and CCF are difficult due to the irregular nature of CCF and its varying timeframes, development stages, age classes, mix of species, products and services. The very terms used by CCF practitioners such as "irregular" forest management and "close to nature" forest management give an indication of the difficulty in modelling such a process. Even where comparisons have been made, there are many assumptions and limitations which render the analyses as theoretical rather than conclusive. What this paper has attempted is to explore the issues which affect the valuation process and to discuss these in the context of CCF management. There is considerable experience to date with regard to many of these issues and where possible this has been reviewed. Further research is needed to develop stand based growth and yield models that can capture the complexity of interactions that occur in CCF stands. In the meantime, accurately assessed case studies of CCF practice, such as the AFI network, can be useful in demonstrating its economic strengths and weaknesses and more such studies over longer timeframes will become increasingly important in this regard.

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The development of a site classification for Irish forestry

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Abstract

Criteria and site classification methods to assist in the identification of land that have potential for afforestation grant aid were evaluated in this study. The study examined the nature, fertility and productivity of unenclosed land to determine if opportunities existed for future afforestation. Local variability in soil nutrient regime and the changing nature of land-use in Ireland may have contributed to some of the observed variability in productivity potential. The results indicated that classifications based on historical enclosures provided limited scope for evaluating the potential suitability of sites for forestry. Therefore, alternative site classification methods, based on productive criteria, were evaluated. Results indicated that the classification of soil nutrient regime, supplemented with indicator plant analysis, showed the greatest potential. A new classification was developed, which was heavily influenced by ecological classifications but with supplementary classes to cover less fertile but still productive site types. The newly-developed classification has seven classes (referred to as site types A to G, in order of decreasing suitability). Sites classed from A to C were typically arable land, improved pasture and "rush-pasture", and offer the potential to diversify species selection. The D type, typically associated with bracken (*Pteridium aquilinium*), is considered potentially suitable for more diverse conifers including Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), western red cedar (*Thuga plicata* D. Don), and western hemlock (*Tsuga heterophylla* (Raf.). The wetter site types with rush (*Juncus* spp.) are suitable for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) assuming a single application of phosphorus. The E site type is typically associated with pure *Molinia* spp. requiring phosphorous fertilisation to support productive Sitka spruce. The F type was considered unsuitable for pure Sitka spruce without the use of nursing mixtures of lodgepole pine (*Pinus contorta* Douglas ex Loudon). Site type G, the lowest classification level, was unsuitable for forestry.

Keywords: *Afforestation, soil nutrient regime, forest productivity, historical land use, field enclosures.*

Introduction

Significant progress has been made in the restoration of forest cover in Ireland over the past 100 years from 1% of the land area that existed in the early 1900's, to 11% in 2015. Further commitments to increase the forest area to approximately 1.2 million ha or 18% of land area were reaffirmed in the 2014 forest policy review document *Forest Products and People* (DAFM 2014). Its achievement will require the annual creation of 16,000 ha of new forests per year up to 2046. The availability of land for forestry expansion however, cannot automatically be assumed and will be highly

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dependent on what is currently considered marginal for agricultural production. Land is a valuable resource and areas suitable for forestry may not necessarily become available, especially if its current use is considered optimal or suitable for future expansion/intensification of agriculture. Other land may be readily available for afforestation in areas where farming activity levels and profit margins are low. The inclusion of a significant proportion of unenclosed land (c. 178,000 ha) which is not subject to National or EU designations but which shows good levels of potential productivity would also provide candidate areas (Farrelly and Gallagher 2015; this issue). To ensure satisfactory establishment and productivity, and to qualify for state afforestation grant aid, the limiting criteria are that land should have the ability to produce a commercial crop of Sitka spruce[1] (*Picea sitchesis* (Bong.) Carr.) with a minimum growth rate of General Yield Class (GYC) 14, as per to Edwards and Christie (1981) (Anon. 2011).

Much attention has been devoted to the performance of forests on unenclosed land. Historically, forestry has been associated with sub-marginal and marginal agricultural land in Ireland, as early land-use policy, overseen by the Land Commission, retained the best areas for food production (Gray 1963). The performance of tree crops on marginal land has been variable. Good quality crops of Sitka spruce and other species have been produced on the lower slopes of mountains and valleys, or on mineral soils derived from Ordovician or Silurian shale and mixed sandstone and shale, or where land was limited in its use for agriculture by the nature of the terrain (e.g. steep rocky slopes, or impeded drainage). Afforestation programmes, which had a stronger emphasis on creating rural employment, resulted in the afforestation of poorer peatland sites in the 1960's, which while able to support coastal provenances of lodgepole pine (*Pinus contorta* Douglas ex Loudon), were unsuitable for pure Sitka spruce crops without multiple fertiliser applications. It is likely that such experiences may have created an impression that peatland sites were inherently unproductive and associated with unthrifty crops. However, certain under-utilised, abandoned, and/or semi-improved land, not already in agricultural use and therefore currently unenclosed, may still provide suitable and productive sites for forestry.

The enclosure of land for agricultural use in Ireland

Historically field enclosures have been used as a basis of demarcation of property boundaries in continuous use for food or animal production. While enclosure of land for agricultural use has long characterised the Irish landscape, it was not until the post-plantation period during the agricultural revolution that the extent of land enclosure and field demarcation were most marked (Aalen and Whelan 1997). Differences in

[1] Sitka spruce was chosen as the benchmark species for afforestation grant aid by the Irish Forest Service to serve as an indicator of whether a commercially viable crop of tree species could be established at a site.

field enclosures between the richer east and the poorer west of Ireland are apparent. In Leinster, the necessity for the demarcation of property boundaries following the establishment of the landlord system in the 17th century, led to the development of regular enclosures. All land below 150 m in elevation that was not bog was enclosed in Leinster by 1850. Tillage enclosures tended to be smaller than pasture fields, the latter enclosed by stock-proof earthen banks and hedges often dominated by hawthorn (*Crategous monogyna* Jacq.), ash (*Fraxinus excelsior* L.) and furze (*Ulex europaeus* L.). In Munster, the pattern was for farms with irregular strips enclosed by walls or banks with exotic plant escapees such as fuscia (*Fuchsia magellanica* Lam.), butterfly bush (*Buddleja davidii* Franch.) and monbretia (*Crocosmia × crocosmiiflora* (Lemoine) N.E.Br.) in west Cork and Kerry, while in east Waterford through to Cork, substantial hedges composed of hawthorn, blackthorn (*Prunus spinosa* L.) and furze were evident. The Golden Vale, an area of rolling pasture land occurring in Limerick, Tipperary and Cork, was composed of larger fields, with hawthorn, blackthorn and ash evident in hedgerows. Areas with dairy enterprises tended to have smaller field sizes for the purposes of shelter, maintenance of fresh grass and management of meadows. In Connaught field formation culminated only in the 19th century and sizes varied in size and shape, from the regular to the highly irregular. In the lowlands, fields were laid out in blocks, large fields with flimsy dry stone walls, often one stone thick. On hillsides, fields were arranged in parallel strips or in ladder-like formation running down the slopes with farmsteads arranged in lines along new roads. The trend in Ulster followed the pattern described for Connaught, with only the best land being enclosed by the end of the 18th century; later land was enclosed with regular small to medium fields bounded by hedged banks. Regular field systems in the lowlands with neatly pruned hedges were common and narrower ladder farms were utilised in the uplands of Donegal, the Antrim Glens and the Sperrin mountains. Little change in field systems occurred until the 1950's when farm mechanisation increased substantially. The pressure to remove boundaries and enlarge fields grew steadily and was directly supported initially by Government grants and by European incentives from the 1960's onwards. Banks and walls were bulldozed and the stones and earth spread over the fields; some were replaced with stone and wire fences, more easily re-arranged for the purposes of strip grazing. Over more recent decades, there has been a significant reduction in field boundary lengths resulting in larger farms. Recent incentives to promote farming in harmony with the environment (i.e. the Rural Environmental Protection Scheme) have resulted in some boundaries being restored or replanted. Historically, land beyond agricultural cultivation and reclamation, considered unsuitable for domestic livestock rearing, was often fenced out or ex-closed. Roughly 20% of the land area of Ireland is thought to be outside of permanent enclosures (Aalen and Whelan 1997).

Potential of unenclosed land

Farrelly and Gallagher (2015, this issue) concluded that 850,000 ha of unenclosed land was biologically unsuitable for forestry expansion, being comprised of deep peat, raised bogs, fens, bare rock and outcrops or currently subject to National and EU designations and policies. However, they concluded that an area of almost 180,000 ha of unenclosed land had good potential for afforestation. While the division of land probably indicates some degree of improvement effort which may influence soil fertility, in itself this does not provide sufficient information to determine if land is inherently suitable or unsuitable for afforestation. Other more objective methods are therefore required for the assessment of suitable sites for forestry (Gallagher 1972, Farrelly 2011, Farrelly and Gallagher 2013).

Much information regarding the suitability of hill and mountain land (much of it unenclosed) for afforestation has been available from Gallagher's 1972 study where marginal and submarginal land of north Co. Wicklow was surveyed and mapped in order to identify various categories of land suitable for forestry development. These included hill farm land adjoining enclosed fields often characterised by grass, bracken and furze. Land above the last wall, ditch or fence defining the boundary between the farm and the open mountain (e.g. upper slopes or hilltops) was often indicated as being suitable for afforestation. Grass slopes with little or no peat and areas lying down-slope from heaths, perhaps indicative of animal grazing and *Molinia* swards perhaps suggested past tree cover. Other areas, due to their geographic/topographic and natural disposition on more favourable south facing slopes located on soils derived from better quality parent material, were deemed favourable for forestry. Other land, with vegetation associated with higher levels of improvement (i.e. soft rush (*Juncus effusus* L.), birch (*Betula* spp.) and furze (*Ulex* spp.), may have been used in the past for stock rearing and then "abandoned" and allowed to revert to scrub and may also indicate suitable sites. Farrelly (2011), in his study of site quality and the productivity of Sitka spruce in Ireland, found that the effect of even limited soil conditioning from past grazing or more limited anthropogenic activities, markedly altered the availability of nutrients in unenclosed land, providing satisfactory conditions for Sitka spruce growth.

Potential methods of classifying suitable site types for afforestation

It is clear from the above that there is a need to more thoroughly examine criteria to describe the nature of unenclosed land and its potential forest productivity, as underpinned by scientific measures of site quality. A range of effective site classification methods are available for the assessment of site quality and forest productivity (e.g. Carmean 1975, Farrelly et al. 2009). These include vegetation-based site classification schemes, such as those proposed by Mark Loudon

Anderson (Anderson 1960), that have been used as an aid to tree species selection in state land acquisition enterprises during the 1960's. Other classifications based on a historic land use from assessments of Ordnance Survey maps (OCarroll 2012) have since been widely used to identify areas of improved soil fertility and were used as the basis for fertiliser prescriptions (OCarroll 1975). More sophisticated soil and vegetation based methods are used to assess site quality and have been used in the Biogeoclimatic Ecosystem Classification (BEC) in British Columbia and the Ecological Site Classification (ESC) in Great Britain (Pojar et al. 1987, Pyatt et al. 2001. The latter method has been adapted to assess site quality and species choice for Ireland, including information on the potential effects of climate change on tree growth responses (CLIMADAPT) by Ray et al. (2009). Both these classification systems are based on multiple factors but rely on a local assessment of soil quality, notably soil moisture and nutrient regime. Soil nutrient regime[2] (SNR) can be assessed using vegetation and/or soil morphological characteristics and can be used to produce a reliable classification of soil fertility (Wilson 2013). The use of the indicator plants to determine soil fertility can produce similar results to those derived from expensive laboratory analysis of soil samples (Wilson et al. 2001, 2005). Such assessments of soil fertility make use of indicator value scale produced by Ellenberg (1988) to describe the soil preferences of vascular plants in Central Europe using a scale that ranges from 1 to 9. More recently indicator values for vascular plants in Britain have been produced and Ellenberg's original values have been revised based on an extensive analysis of conditions in Great Britain, referred to as Hill-Ellenberg values (Hill et al. 1999). While three indicator values explain soil moisture (F-value), soil reaction or base status (R-value) and nitrogen (N-value) status, the combined values for base status and nitrogen (R+N value) are often used as a composite indicator of soil nutrient status (Pyatt et al. 2001). The assessment procedure follows a numerical procedure to produce a unit-less weighted average indicator value which provides a reliable classification of the nutrient status of soils (Wilson 2013).

Other soil-based classifications based on traditional soil survey methods have been widely used to assess soil quality and gained much favour in the 1970's and 80's in Ireland (O' Flanagan and Bulfin 1970, Bulfin et al. 1973, Carey et al. 1985, Bulfin 1987, Conry and Clinch 1989). The classification of soils into great groups or to soil series level is also useful for assessing soil quality and provides information on the inherent fertility status of a soil, available water capacity, associated vegetation, parent material type, drainage, texture, depth and structure. For example, Bulfin et al. (1973) estimated rates of Sitka spruce production based on a map of soil series from the Leitrim Resource Survey carried out by An Foras

[2] Soil nutrient regime as described by Klinka et al. (1984).

Taluntais (now Teagasc) in the 1970s. While soil classification is an excellent proxy for site fertility, it requires a detailed survey and considerable expertise to classify soils especially to soil series level. Farrelly (2012), in a study of soil quality and Sitka spruce productivity showed that more detailed classification of soils into soil subgroups (twenty classes) was more successful in explaining variability in yield than the currently used, more expensive analytical measures of soil quality (i.e. soil pH, soil P, K, Mg and N), due to the spatial variability of soil properties.

Objective of the study
The objective of the study was to examine the nature, fertility and productivity of unenclosed land and identify if opportunities exist for future afforestation. A further objective was to examine if criteria or site classification methods exist that can be used to assess whether a site would be capable of producing a commercial crop and qualify for afforestation grant aid. To be of any practical use in forest management, a site classification method must (1) explain at least 50% of the variation in yield class; (2) be based on a few easily measured variables (Blyth and MacLeod 1981); and (3) be capable of reliably and consistently classifying areas for afforestation grant aid. The ultimate objective of the study was to develop a site-level classification specifically for use in Irish forestry.

Materials and methods

Characterisation of historical agricultural land use
To examine the productivity of land and its relationship with historical land enclosure, an assessment was made of a representative sample of land planted with Sitka spruce[3] (including both enclosed and unenclosed areas) across Ireland (Farrelly 2011). Stands were selected for study from the entire range of pure Sitka spruce crops that were even-aged, uniformly stocked, and at post establishment stage (stand age ranged from 15 – 82 years) and covered both Coillte (State owned) and privately owned forests. In total, 201 stands were visited between October 2006 and April 2009. Prior to field visits, information on historical land use was assessed from Ordnance Survey of Ireland (OSI) 6-inch and 25-inch maps covering four editions published from 1829 to 1948 (Table 1). Details regarding field enclosures and land use were derived from each OSI map edition and subsequent editions were compared in an effort to identify the degree of change in land use from first to last edition (i.e. over 120 years). Stands were designated according to enclosure type and fertility class based on this assessment of map ornament according to OCarroll's (2012) simple site fertility classification (A, B, C, X). Further information about field size and elevation were also recorded from the OSI maps.

[3] Sitka spruce is used as a benchmark species for afforestation grant aid by the Irish Forest Service.

Table 1: *The various editions of the Ordnance Survey of Ireland (OSI) 6-inch and 25-inch maps published from 1829 to 1948.*

OSI Map Edition	Approximate date
OS 6-inch 1st edition	(c. 1829-1841)
OS 25-inch 1st edition	(c. 1897-1913)
OS 6-inch sub edition	(c. 1913-1848)
OS 25-inch final edition	(c. 1913-1948)

Collection of field data

Stands were visited and sample plots 0.04 ha (20 × 20 m) were randomly located a minimum of 10 m from stand edges. Soil type was categorised into great group and sub-group according to Gardiner and Radford (1980) by digging a soil pit at the centre of each plot as far as the C horizon (parent material) or to the depth of an impermeable layer, whichever was encountered first. Vegetation occurring on plots was assessed using the indicator-plant procedure according to Pyatt et al. (2001). All plant species present within the sample plot, except those growing on decaying wood and or exposed rock, were identified and their percentage cover was estimated with the aid of species abundance charts (Klinka et al. 1984). Plants that could not be identified were collected for later identification. Species occurring in the tree layer (not including the planted crop), shrub layer, ground layer and epiphyte layer were recorded. Grass species were also recorded, where possible. The total vegetation cover was calculated for the plot by summing the percentage cover of all species in plots. In some sample plots no vegetation cover was present due to dense canopy cover, in other cases, the total percentage cover could exceed 100% cover, where layered vegetation was present (e.g. presence of shrub and field layers). Each species was then allocated a Hill-Ellenberg indicator value for nutrient (N), and soil reaction (R) (Hill et al. 1999). For each plant the abundance was multiplied by the combined R and N value (R+N), summing by the products and dividing by the sum of the abundances for each plot to calculate the weighted average mean indicator value (mR + mN). There was sufficient vegetation cover at 145 plots to calculate abundance-weighted mean indicator values. For the purposes of this study, (SNR) was calculated for all plots (and classified as very poor, poor, medium, rich or very rich) using a combination of soil morphological properties (Klinka et al. 1984) and by converting mean indicator values (where available) to the appropriate soil nutrient classes for ESC in Great Britain (see Pyatt et al. 2001, p. 26). Relationships between SNR and historical land use were also examined to assess the nutritional status of enclosed and unenclosed land.

Assessing forest productivity

Within each plot, top height[4] (the mean height of the 100 largest diameter trees breast height per hectare) was estimated as the mean height of the four largest DBH trees (Edwards and Christie 1981). Height was measured by using a Vertex IV Hypsometer and transponder. Crop age was obtained from management records. GYC was assessed using top height and crop age curves for Sitka spruce according to Edwards and Christie (1981).

Data analysis

The General Linear Model (GLM) procedure in SAS (SAS 2009) was used to examine the strength of relationships between GYC and site classification criteria (i.e. soil group, fertility class, mean indicator values (mR + mN) and SNR). Differences between the categories of the various qualitative variables were tested by comparing differences between least squares means.

Site classification procedure

To develop a practical site classification method for use in Irish forestry, only classifications that explained at least 50% of the variation in yield class and/or offered the possibility of delineating minimum productivity thresholds were selected. In addition, further criteria were added, which included the classification of site types that require fertiliser inputs to support tree growth. It may be necessary to consider combinations of two or more classifications to achieve these criteria. A description of soil and vegetation types found associated with each of the site types is also provided.

Results

Characterisation of historical land use

The data suggest that there has been a considerable change in land use in Ireland over the last two centuries, most likely due to population expansion in pre-famine times up to 1845, followed by land abandonment as population pressure lapsed in the middle to late 19th century. Of the 201 sites examined, land use in 1829-1841 was classified as shown in Table 2. An examination of land use on the 1913 to 1948 maps indicated that, of the 113 sites classified as being bog or uncultivated ground on the 1829 to 1841 maps, only 79 of the sites remained so on the 1913-1948 maps, i.e. 23 sites had been permanently enclosed and were used in cultivation, eight sites were enclosed and used for rough pasture and three sites were classified as being woodland by 1913-1948 (Table 3). It was also evident that some land previously classed as being enclosed (i.e. as cultivated ground) on the 1st edition of the OS maps had been abandoned by 1913-1948 and had reverted to rough pasture (22 sites). Of the 18 sites classified in 1829-1842 as being enclosed with bog or uncultivated

[4] Referred to as dominant height in USA and Canada.

Table 2: *The number of sites classified according to the OSI 6-inch 1st ed. categories (1829-1841).*

OSI 6-inch map ornament (1829-1841)	No. of sites
Bog or uncultivated ground	113
Enclosed land with bog or uncultivated ground[a]	18
Enclosed with cultivated ground	54
Woodland and scrub	16

[a] This indicated that land was stock proof but relatively unimproved otherwise.

ground, five had been reclaimed by 1913-1948. Deforestation was evident as two of the sites no longer had woodland present by 1913-1948 map edition.

Average field size (from OSI 1913-1948 maps: recorded in acres but converted to hectares) was 12.6 ha; in 75% of cases, field size was found to be less than 20 ha and larger fields were found to be mainly associated with old demesnes (Table 4). The area of land outside permanent enclosures was recorded (on the maps) in 23% of cases, indicating an effort to map holdings. Where an area was recorded it ranged from 9 to 910 ha, with an average size of 124 ha. On average, land in permanent enclosure was found at elevations from 9 to 362 m (Table 4). Land outside permanent enclosure was found to occur from 34 to 583 m in elevation.

The range of soils found on unenclosed land was quite variable, with all major soil groups being found. Of the sites sampled, 52% of the soils were classified as blanket peats and lithosols, so had an extremely limited potential for agriculture and forestry use. A further 35% of the sites sampled were found to have soils with more potential for forestry (i.e. the peaty gleys, peaty podzols, and basin peats). A further 15% of sites visited contained soils that were classified as being very suitable for a range of forest species and were likely to result in very high timber

Table 3: *Land use change from 1829-1842 to 1913-1948, based on data from historic OSI maps.*

OSI map ornament (1829-1841) classification		OSI map ornament (1913-1948) classification			
		Unenclosed with rough pasture or whin	Enclosed cultivated fields	Enclosed with rough pasture	Woodland
Bog or uncultivated ground	(113)	79	23	8	3
Enclosed bog or uncultivated	(18)		5	11	2
Enclosed with cultivated ground	(54)		26	22	6
Woodland and scrub	(16)		1[a]	1[a]	14
Total for 1913-1948	**(201)**	**79**	**55**	**42**	**14**

[a] Indicates deforestation.

Table 4: *The numbers of samples with areas recorded and the range in elevation on OSI 25-inch maps, according to enclosure type in Ireland (based on a sample of 201 stands).*

Closure type	No. with area (%)		Field size (ha)			Elevation (m)		
			Min	Max	Mean	Min	Max	Mean
Enclosed	108	(100%)	0.32	153	14	9	362	161
Outside enclosure	18	(23%)	9	910	124	34	583	265
Woodland	6	(43%)	1	24	11	20	116	64

yields (i.e. brown earths, brown podzolics, gleys and podzols) (Table 5). An analysis of the vegetation composition of unenclosed sites (Table 6) indicated that 25% of sites examined had vegetation associated with cutover raised bog (i.e. bracken, gorse, birch) and grassland. Over half of the sites examined (52%) were classified as having vegetation associated with blanket and raised bogs and lithosols, and thus were considered to have very limited forestry potential.

Relationship between forest productivity and site classification
All site classification methods successfully predicted the productivity of Sitka spruce ($P<0.001$), but some methods were better than others. Soil classification according to great group showed a significant relationship with GYC ($P<0.05$; $R^2_{adj} = 0.30$) but was insufficient for delineating minimum productivity thresholds (i.e. as no soils showed

Table 5: *The range in soil groups and suitability for forestry of land outside permanent enclosure, as assessed on OSI 25-inch maps.*

Suitability for forestry[a]		Soil groups	No. of sites	Proportion
Very limited	(GYC ≤14)	Blanket peat high level	29	36.7%
		Blanket peat low level	8	10.1%
		Lithosol	4	5.1%
Moderate	(GYC 14-20)	Peaty gley	10	12.7%
		Peaty podzol	8	10.1%
		Peaty-ironpan-podzol	2	2.5%
		Basin peat cutover	7	8.9%
Wide	(GYC 20+)	Acid-brown earth	2	2.5%
		Brown earth	2	2.5%
		Brown podzolic	3	3.8%
		Gley	1	1.3%
		Podzol	2	2.5%
		Rendzina	1	1.3%

[a] Assessed using general yield class (GYC) in $m^3\ ha^{-1}\ yr^{-1}$.

Table 6: *Vegetation types on land outside agricultural enclosure assessed on OSI 25-inch maps and their suitability for Sitka spruce afforestation (source Farrelly and Gallagher 2013).*

Suitability for forestry	Vegetation type/habitat	No.	Proportion
Very Limited	Lowland blanket bog	8	10.1%
	Upland blanket bog	28	35.4%
	Raised bog	2	2.5%
	Rock complex	3	3.8%
Limited [a]	Dry mineral soils with shrub/heath	9	11.4%
	Wet mineral soils with shrub/heath	9	11.4%
Moderate	Cutover raised bog	4	5.1%
Wide	Dry grassland	12	15.2%
	Wet grassland	4	5.1%

[a] Other species (i.e. Scots pine, western hemlock, etc.) may be more suited to these site conditions, where Sitka spruce may prove unthrifty.

GYC <14). The simple site classification (fertility class) based on map ornament was only moderately more successful at explaining the variability in yield ($P < 0.05$; $R^2_{adj} = 0.325$). The classification showed that productivity reduced with declining land management. Higher levels of productivity were found on land classified as enclosed and cultivated (fertility class A), with an average GYC of 25.2 $m^3\ ha^{-1}\ yr^{-1}$. Productivity was found to be significantly lower ($P < 0.05$) on enclosed land with furze (fertility class B) where GYC was 19.5 $m^3\ ha^{-1}\ yr^{-1}$. On land with no evidence of enclosure with rough pasture and/or outcropping rock (fertility class C), GYC was 15.6 $m^3\ ha^{-1}\ yr^{-1}$ (the confidence interval (0.05 level) was 14.2 – 17.0 $m^3\ ha^{-1}\ yr^{-1}$) (Figure 1). However, there was considerable variability in yield on unenclosed land (fertility class C) with levels of production varying from GYC 4 – 30 $m^3\ ha^{-1}\ yr^{-1}$ (the median value was 16 $m^3\ ha^{-1}\ yr^{-1}$) and 64% of sites had yields in excess of 14 $m^3\ ha^{-1}\ yr^{-1}$ (Figure 2). As the method was insufficient for delineating minimum productivity thresholds (i.e. with a GYC ≤14), its usefulness was limited.

The use of indicator species improved the relationship with GYC and explained slightly more of the variability in yield ($P < 0.05$; $R^2_{adj} = 0.36$) (Table 7). Higher GYC values were associated with increasing mean indicator values indicating increasing yield with increasing fertility (Figure 3). More interestingly, the method showed potential for delineating minimum productivity thresholds, with the minimum threshold for GYC of 14 occurring at the combined mean indicator value (i.e. mR + mN) value of 5[5] or above. Soil nutrient regime derived from a combination of soil

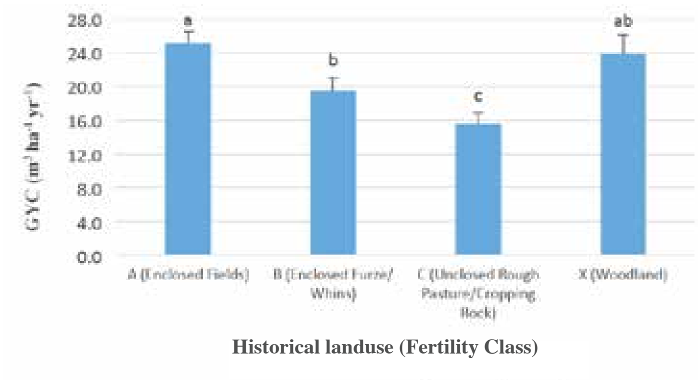

Figure 1: *Potential productivity of Sitka spruce, using general yield class (GYC), in relation to historical land use as per OCarroll's (1975) fertility classification. Error bars represent 95% confidence intervals (different lowercase letters denote significant differences between groups).*

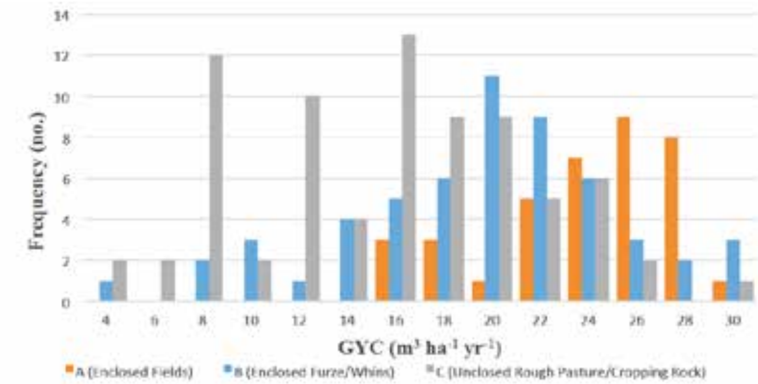

Figure 2: *The variability in yield class of Sitka spruce in relation to historical land use as per OCarroll's (1975) site fertility classification based on OSI map classifications.*

morphological properties and mean indicator values showed the strongest relationship with GYC of all variables examined (P <0.05; $R^2_{adj} = 0.51$) (Table 7). GYC increased significantly as site types moved from very poor to very rich (i.e. sites with increasing nitrogen availability) (P <0.05), with the maximum achievable GYC occurring on very rich sites (Figure 4).

Nutrient status in relation to historical land use

SNR had a close relationship with historical land use type. Figure 5 shows that considerable variability in fertility exists associated with both enclosed and unenclosed land. SNR was found to range from very poor (VP) to rich (R) on unenclosed land,

[5] The methodology results in a unit-less scale of index values from 1 to 9.

Table 7: *Significance and strength of relationships between mean indicator values (mR+mN) and soil nutrient regime and general yield class.*

Indicator species (mR+mN)						
Source	df	SS	Mean square	F	Pr >F	VE[a] (%)
Model	1	2250.1	2250.06	79.22	<0.001	36.0
Error	143	4061.8	28.40			
Soil Nutrient Regime						
Source	df	SS	Mean square	F	Pr >F	VE[a] (%)
Model	5	4658.2	931.64	40.77	<0.001	51.1
Error	195	4456.3	22.85			

[a] Percent of the variation explained by the source variable.

with poor being the most frequent category. For enclosed sites SNR ranged from very poor to rich, but was most commonly medium. While it was clear that the effect of historical land use (and its effects on nutrient and soil condition) may markedly alter increased availability of nitrogen, sufficient variability existed to suggest that the fertility status of unenclosed land could be highly variable. The possibility of using soil type to classify SNR is demonstrated in Table 8; however, some soils show considerable variability in SNR.

Subdivision of very poor SNR sites

It was recognised that the changing land use patterns and variability in nutrient regimes associated with unenclosed land may require a sub-classification of sites already classified as being very poor. This was to accommodate sites which were

Table 8: *Classification of the range in soil nutrient regime (SNR) and corresponding site types (A to G) for great soil groups in Ireland based on 70% of soils within a soil group achieving the stated soil nutrient regime.*

Great soil group	**Range in SNR[a]**	**Site type**
Basin peat	P-R	D-B
Blanket peat	VP-P	G-D
Brown earth	M-VR	C-A
Brown podzolic	M	C
Gley	P-R	D-C
Grey brown podzolic	R-VR	B-A
Lithosol	P	D
Podzol	P-M	D-C
Rendzinas	R	B

[a] SNR classes: VP, very poor; P, poor; M, moderate; R, rich; VR, very rich.

weakly ericaceous (dominated by *Molinia caerulea)* but may have potential for Sitka spruce which are currently classified as very poor SNR within the ESC scheme (Pyatt et al. 2001). The indicator value given to *Molinia caerulea* within ESC is perhaps too low as traditional foresters had believed that it indicated conditions suitable for pure spruce with limited P and N (Cadman 1953, Anderson 1960, Condon 1961, Wilson 2013). Furthermore its indicator value of 5 appears at or near the threshold for production of Sitka spruce with GYC 14 in Figure 3. Therefore, it was necessary to further subdivide the very poor SNR sites as follows:

1. sites that were weakly ericaceous being mesotrophic in nature that may profit from the addition of one or more applications of fertilisers (*Molinia caerulea*, *Carex, Juncus* spp. present);

2. sites classified as being oligotrophic in nature (*Calluna vulgaris, Molinia* spp. present); and

3. sites that were considered infertile or dystrophic (*Trichophorum germanicum*, *Narthecium ossifragum, Eriophorum vaginatum* present, i.e. deep peats).

This vegetation-based classification scheme coresponds with a similar scheme proposed by Taylor and Tabbush for evaluating ericaceous sites to provide guidance on fertiliser requirements to support tree growth and are described in Forestry Commission Bulletin 124 (Taylor and Tabbush 1990).

Development of the classification

Both the classification of SNR and the use of indicator plant analysis show potential

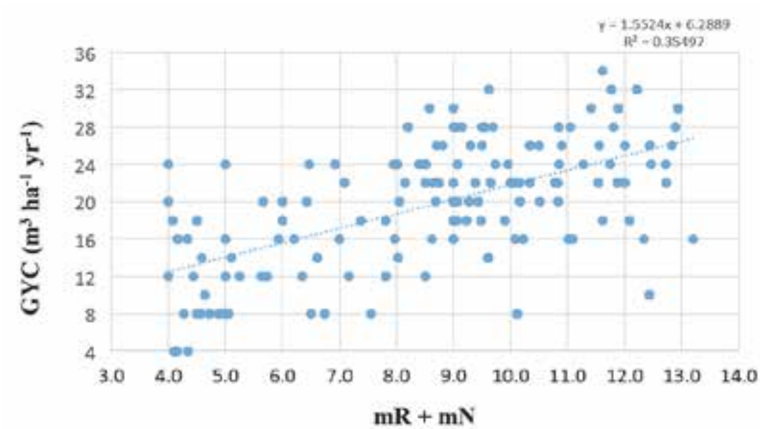

Figure 3: *Regression equation and strength of the relationship (R^2) between Sitka spruce general yield class (GYC) and mean indicator values (mR + mN) for vascular plants in Ireland. Corresponding mR + mN values for GYC 14 are approximately 5.*

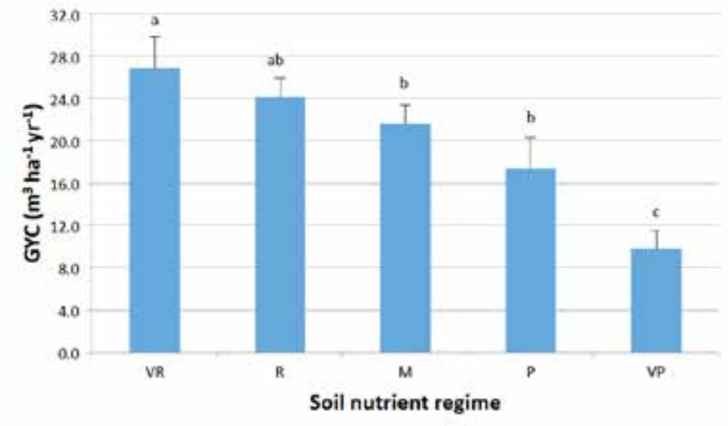

Figure 4: *Productivity of Sitka spruce (GYC) in relation to soil nutrient regime. Error bars represent 95% confidence intervals (different lowercase letters denote significant differences between groups). Soil nutrient regime classes: VR, very rich; R, rich; M, medium; P, poor, VP, very poor.*

for use as they are based on a few easily measurable variables and show potential to classify areas for afforestation grant aid. Considering the success of the SNR criterion in explaining more than 50% of the variability in GYC of Sitka spruce it was selected as the main component of the proposed site classification. Therefore SNR classes A to D, covering very rich to poor site types (as outlined by Pyatt et al. 2001), are proposed. The very poor SNR class (which had a mean indicator value of <5.7) should be replaced by three additional classes (E to G) based on the relationship between mean indicator values

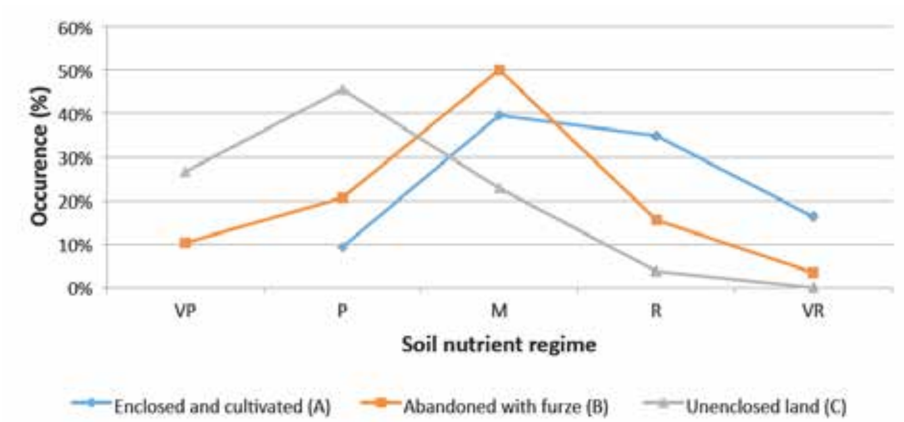

Figure 5: *The occurrence of soil nutrient regimes at sampled sites associated with historical land use (in %) as per OCarroll's (1975) site fertility classification based on OSI map classifications. Soil nutrient regime classes: VR, very rich; R, rich; M, medium; P, poor, VP, very poor.*

Table 9: *Site classification for forestry in Ireland, as proposed by Farrelly and Gallagher (2013).*

Site type	Forestry potential	Nutrient class	Soil groups included	Mean indicator value[a]	Yield class $m^3\ ha^{-1}\ yr^{-1}$	Fertilizer requirement[a]	Species suitability[b]
A	Very wide	Extremely fertile (hyper eutrophic)	Grey brown podzolics, brown earths, some reclaimed fen peats	>11.7[c]	>26	None	SS and diverse broadleaved spp. and conifers
B	Wide	Very fertile (eutrophic)	Grey brown podzolics, brown earths, some brown podzolics, some gleys, reclaimed podzols and peats	9.7-11.6[c]	22-26 (24)	None	SS and diverse broadleaved spp. and conifers
C	Moderately wide	Moderately fertile (sub eutrophic)	Brown earths, brown podzolics, gleys, some peaty gleys, some reclaimed podzols and peats	7.7-9.6[c]	18-22 (20)	None	SS and diverse conifers
D	Somewhat limited	Poor to moderately fertile (mesotrophic)	Peaty gleys, peaty podzols, lithosols, cutover blanket peats	5.7-7.6[c]	14-18 (16)	P	SS, NS, WRC, WH, MP, DF, GF
E	Limited	Moderately infertile (sub mesotrophic)	Flushed blanket peats, gleys, peaty podzols, lithosols, some peaty gleys	5.0-5.6[c]	14	P,P	LP, SS
F	Very limited	Very infertile (oligotrophic)	Blanket peats, some peaty gleys, peaty podzols, lithosols	4.0-4.9[d]	10-12	P,P,N	LP
G	Extremely limited	Extremely infertile (dystrophic)	Intact blanket peats/raised bogs	<4.0[4]	-		

[1] Fertiliser requirement: P -phosphorus requirement at planting; P,P -Phosphorus requirement at planting and thereafter; P,P,N -Phosphorus and (possibly) nitrogen requirement at planting and/or thereafter. [a] average weighted indicator value for base reaction and Nitrogen

[b] SS -Sitka spruce; WRC -western red cedar; WH -western hemlock; NS -Norway spruce; DF -Douglas fir; GF -grand fir; MP -Macedonian pine; LP -lodgepole pine.

[c] mR + mN values as proposed by Pyatt et al. (2001).[d] mR + mN values as proposed by Farrelly and Gallagher (2013).

and Sitka spruce GYC, and a vegetation-based classification scheme that coincides with the British scheme for evaluating ericaceous sites (Taylor and Tabbush 1990):

D. sites with mean indicator values of ≥5 and <5.7 suitable for Sitka spruce, and are weakly ericaceous.

E. sites with mean vegetation indicator values between 4 and 5 which require two or more applications of mineral fertiliser to support tree growth (Taylor and Tabbush 1990).

F. sites with mean vegetation indicator values <4 that are the most infertile sites where pure spruce stands should not be planted.

A new site classification for Irish forestry

This forest site classification is outlined in Table 9 with key indicator species groups presented in Table 10. A more detailed description of each site types follows:

Site type A

This type incorporates all land managed under intensive agricultural systems. Cultivated and fertilised fields, used for tillage, crops, and pasture grazing are included (as well as areas reclaimed for grazing). Soil types are grey brown podzolics and calcareous brown earths with some reclaimed fen peats. Sites tend to be mainly well drained. Vegetation is mainly composed of mixed grassland including *Agrostis* spp., *Lolium perenne, Dactylis glomerata, Poa annua, Trifolium* spp., *Cirsum* spp. *Rumex* spp.*, and Urtica dioca*.

Site type B

This type incorporates all land moderately suitable for tillage crops and pasture grazing, but also suitable for a wide range of forest crops. Sites are generally cultivated fields. Vegetation is grassland (dry and wet grassland). Soils include the less fertile grey brown podzolics (slightly degraded) and calcareous brown earths, acid brown earths and some reclaimed podzols/basin peat soils. Soil drainage varies from being well to poorly drained. Vegetation is predominantly mixed grassland, included *Holcus lanatus, Festuca rubra, Brachypodium sylvaticum, Cynosurus cristatus, Poa pratensis*. *Juncus effusus* may be present but never dominates.

Site type C

This type incorporates all land moderately to poorly suited for tillage, but moderately suitable for pasture grazing and for forestry. Soils include acid brown earths/brown podzolics/podzols and typical surface water gleys, peaty gleys and reclaimed peats. Vegetation is predominantly poorer grassland composed of *Agrostis* spp., *Deschampsia cespitosa, Brachypodium sylvaticum, Holcus lanatus, Festuca rubra,* *Cynosurus cristatus, Poa pratensis and Oxalis acetosella* species. *Ulex europaeus* L. often re-invades following reduced management. On the wet grassland sites or areas of reclaimed peatland, *Juncus effusus* becames dominant.

Site type D

This type incorporates all land poorly suited for tillage, moderately to poorly suited to pasture and somewhat limited for forestry. Land may some show evidence of improvement. Soils are peaty gleys, peaty podzols, flushed/improved blanket peats, some brown podzolics and gleys. Dense bracken (*Pteridium aquilinum*) is a key indicator and often forms a dense cover on hillsides. Sweet vernal grass (*Anthoxanthum odoratum*) occurs on old hill pastures. Wetter areas include rushes (*Juncus acutiflorus, J. conglomeratus and J. bulbosus)* and are suitable for Sitka spruce. Ericaceous species are largely absent.

Site type E

Site class E incorporates all land poorly suited for pasture and are moderately to poorly suited for extensive grazing. Soils are mostly peaty or peat soils. Purple moor grass (*Molinia caerulea*) is one of the key species represented in this site type. Other species indicative of this site type are *Carex* spp., *Deschampsia flexuosa,* Mat-grass (*Nardus stricta*) and western gorse (*Ulex galii*). Sites must have either have pure swards of *M. caerulea* with a proportion of "better" plant species, such as *Juncus effusus, J. squarrosus, Anthoxanthum odoratum, Agrostis* spp. *or Rubus fruticosus* L., the presence of which increases the fertility of the site.

Site type F

Site class F incorporates all land classified as having extremely limited potential for agriculture and forestry. Soils are mostly peats. Vegetation is typical of blanket bogs or wet/ dry heath being strongly ericaceous, with *Calluna vulgaris, Vaccinium myrtillus* L.*, Molinia caerulea, Erica tetralix* L.*, E. cinerea* L.*, Juncus squarrosus*, *Eriophorum angustifolium* present

Site type G

Site class G incorporates all land classified as having no potential for agriculture or forestry and considered unplantable. Soils included intact blanket bogs or raised bogs. Sites are characterised by very poor drainage and a watertable at or near the surface. Water pools occur frequently on the surface of blanket bogs and the presence of *Racomitrium mosses* and *Cladonia* spp. (lichens) and *Drosera* spp. (sundews) are characteristic. *Narthecium ossifragrum*, *Eriophorum vaginatum*, *Trichophorum germanicum* are generally abundant. *Calluna vulgaris* and *Erica tetralix* are usually present and *Schoenus nigricans* is nearly always present on lowland blanket bogs in the west of Ireland.

Table 10: *Characteristic ground vegetation species for use as indicators of site types A to G.*

Site type	Characteristic ground vegetation species	Comon name	Mean Indicator value[a]
A	*Dactylis glomerata*	Cocksfoot	13
	Lolium multiflorum	Italian ryegrass	14
	Cirsium vulgare	Spear thistle	12
	Urtica dioca	Stinging nettle	15
	Rubus fructicusus	Bramble	12
B	*Holcus lanatus*	Yorkshire fog	11
	Dryopteris affinis	Scaly male fern	10
	Primula versis	Primrose	10
	Rubus ideas	Raspberry	10
	Filipendula ulmaria	Meadow sweet	10
C	*Juncus effusus*	Soft rush	8
	Deschampsia caespitosa	Tufted hair grass	9
	Digitalis purpurea	Foxglove	9
	Luzualla sylvatica	Great woodrush	8
	Ranunculus flammula	Lesser spearworth	8
D	*Juncus acutifloris*	Sharp flowered rush	6
	Anthoxanthum odoratum	Sweet vernal grass	7
	Pteridium aquilinum	Bracken	6
	Luzualla campestris	Field woodrush	7
	Blechnum spicant	Hard fern	6
E	*Molinia caerulea*	Purple moor grass	5
	Nardus stricta	Mat grass	5
	Ulex galeii	Western gorse	5
	Carex binervis	Green ribed sedge	5
	Deschampsis flexuousa	Wavy hair grass	5
F	*Calluna vulgaris*	Heather	4
	Vaccinium myrtillis	Bilberry	4
	Molinia caerulea	Purple moor grass	5
	Juncus squarrosus	Heath rush	4
	Erica cinerea	Bell heather	4
G	*Trichophorum germanicum (caespitosum)*	Deer grass	4
	Erica tetralix	Cross leaved heath	3
	Eriophorum vaginatum	Hares tail cotton grass	3
	Narthecium ossifragum	Bog asphodel	3
	Drosera rotundifolium	Common sundew	3

[a] Average weighted indicator value for base reaction and nitrogen (mR+mN).

Conclusions and recommendations

The results from this study suggest that favourable sites in terms of productivity exist on unenclosed land, perhaps attributable to the residual effect of soil conditioning associated with historical land-use or local variability in soil nutrient availability[6]. Classifications based on historical boundaries do not fully reflect local nutrient levels and offer only limited scope to differentiate unenclosed sites (with favourable characteristics for tree growth) from areas with more limited agricultural potential. The newly developed system proposed in this study has been heavily influenced by the Canadian (BEC) and British (ESC) classifications of SNR, but includes some modifications to include additional classification of poorer site types found in Ireland. It satisfies the requirement of being able to explain at least 50% of the variation in GYC, is based on a few easily measurable variables and can be used to reliably and consistently classify areas for afforestation grant aid. The classification of soil nutrient regime in this study showed the strongest relationship with the GYC of Sitka spruce (R^2 = 0.51) and was derived from soil morphological properties and mean indicator values. The procedure gives greater weight to soil properties in the calculation of SNR when vegetation cover is low or absent (Farrelly 2011). There was a weaker relationship between mean indicator values and GYC of Sitka spruce (R^2 = 0.36). While the calculation of mean indicator values was based on vegetation data from 146 plots, in some cases vegetation cover on plots was low (<10%) or available from only a few indicator species. This probably reflects that the reliability of this method is less where vegetation cover on plots is <10% cover (Pyatt 2001).Therefore, the calculation of SNR using a combination of soil properties and vegetation types is recommended (Table 9 and 10) as this will accommodate sites where vegetation cover is limited or modified by grazing or burning practices. Assessment of vegetation by abundance-weighted scoring techniques will allow for more precise assessment especially on difficult sites. The system may succeed in alleviating the difficulties encountered with the assessment of unenclosed sites for their suitability for forestry.

Data from this study showed that some unenclosed land had soil and vegetation characteristics favorable for forestry development, covering an area of up to ~178,000 ha (Farrelly and Gallagher 2015, this issue). Site types D and E are likely to be more suitable than those vegetated predominantly by ericaceous species. Site types F and G are deemed unproductive and they occur on deep peat sites, making them unsuitable for afforestation grant aid. Site classification methods such as those presented here offer the potential to more accurately assess the potential of land for afforestation with a view to matching more carefully to tree species requirements. Such land capable of achieving the minimum threshold for afforestation grant aid may be considered

[5] Nutrient availability is expressed as soil nutrient regime.

suitable for planting. The methodology proposed here can be carried out by qualified foresters who have undertaken specific silvicultural training, preferably with the aid of a field guide.

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The need to disaggregate podzols and peaty podzols when assessing forest soil carbon stocks

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Abstract

Inventories of forest soil carbon (C) stocks are necessary to determine spatial and temporal C stock changes and support climate change mitigation policy development. Afforested podzols and peaty podzols were sampled to measure bulk density (BD) and soil organic carbon (SOC) content with the aim of improving baseline soil C stock estimates for Irish forests. Podzols are not always distinguished from peaty podzols and both qualify as mineral soil types. Distinct differences in mean BD, SOC % and soil C stock values were found between sites with podzols and peaty podzols across the four depths sampled, i.e., 0-10, 10-20, 20-30, 30-40 cm. The estimated soil C stocks for the podzol sites ranged from 129-139 Mg C ha^{-1}, while the peaty podzols had 229-385 Mg C ha^{-1}. The major disparity in the soil C stocks implies the need to disaggregate podzols and peaty podzols in conducting soil C inventories, with the need for development of carbon emission factors for peaty podzols to reduce uncertainty in soil C stock estimates.

Keywords: *Afforestation, soil organic carbon, bulk density, carbon emission factor.*

Introduction

Regional and national scale soil carbon (C) inventories are required to understand soil C dynamics and support climate change mitigation policy development (IPCC 2006, Ogle et al. 2010, Mishra et al. 2012). Sampling of a population involves taking measurements from a select subset of individuals to estimate the properties or parameters of the total population (Pennock et al. 2006). Stratified sampling (Heim et al. 2009), e.g. by soil group (e.g. peat soils, gleys, podzols) and tree species, can be used to reduce the soil organic carbon (SOC) sampling effort. Generally, precision of estimated regional or national SOC inventory values (Mg C ha^{-1}) is increased (i.e. smaller confidence ranges) with increased sampling (IPCC 2006).

Differences in definition and carbon assessment of organic and mineral soils

The Intergovernmental Panel on Climate Change (IPCC) and the Food and Agriculture Organisation (FAO) use similar criteria to distinguish between organic and mineral soils. Organic soils are also known as peatland, bog, muck soils (IPCC 2014). The IPCC mostly use the following FAO guidelines for defining organic soils, but allow

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greater autonomy based on country-specific historical definitions of organic soils (IPCC 2014):

i) have a minimum thickness of 10 cm where overlying rock or ice;

ii) contain at least 12% organic C (~20% soil organic matter (SOM) by weight) for 0-20 cm soil depth where the organic layer is <20 cm deep;

iii) hold >20% SOC (~35% SOM) for normally unsaturated soils; and

iv) have between 12-18% SOC with clay content varying between 0–60% (IPCC, 2014).

In contrast, most European definitions of organic soils stipulate >30% (dry mass) of SOM in layers ≥40 cm deep (Joosten and Clarke 2002, Couwenberg 2009).

The Irish Environmental Protection Agency (EPA) defines organic soils as having >20% SOC and depth >30 cm (Duffy et al. 2014). Teagasc, the Irish Agriculture and Food Development Authority, use a depth >40 cm and sub-divide organic soils with <50% SOC into sandy, loamy and peaty organic soils based on the percentage of clay and sand found (Simo et al. 2008). Northern hemisphere organic soils cover around 3% of the global land area, hold approximately one third of global SOC stocks (Gorham 1991, Turunen et al. 2002) and between 53%-62% of Irish soil's SOC (Tomlinson 2005, Eaton et al. 2008). These C rich soils occupy around 14-17% of Ireland's land area (Connolly et al. 2007, Hammond 1981) and have C stock values for their total estimated depth ranging from as low as 240 Mg C ha^{-1} for lowland blanket peats to as high as 3,070 Mg C ha^{-1} in lowland raised bogs (Tomlinson 2005). Due to their large C stock values, use of soil sampling techniques to measure relatively small changes in C stock can be adversely affected by a low signal-to-noise ratio (Baker and Griffis 2005). Therefore the C flux of organic soils is often assessed via eddy-covariance or chamber based monitoring systems from which emission inventories for carbon dioxide (CO_2) or other greenhouse gas (GHG) fluxes are derived (Alm et al. 2007, Couwenberg 2009). The measured GHG emission quantities together with activity statistics, e.g. land area and afforestation or deforestation rates form the basis of emission factors (EF's) for a studied source/GHG combination (Duffy et al. 2014). An EF of 2.6 t CO_2 ha^{-1} yr^{-1} is reported for forests on drained organic soils in temperate climate/vegetation zones (IPCC 2014), though the EPA (Duffy et al. 2014) use a much lower value based on data from Byrne and Farrell (2005) of 0.58 t CO_2 ha^{-1} yr^{-1}. The EPA also use the same soil EF as above for peaty mineral soils but adjust the EF based on the depth (cm) of the peaty layer.

Alternatively, mineral soils are defined by the EPA as having <20% SOC to a maximum depth of 30 cm and generally have much lower C stocks. For example the top 30 cm (excluding the litter and fine woody debris components) of Irish forested brown earths and gleys have estimated C stocks ranging from 42 Mg C ha^{-1} to 167 Mg C ha^{-1} respectively (Wellock et al. 2011). Tomlinson (2005) also reported Irish mineral soil C stocks ranging from 137 Mg C ha^{-1} to 343 Mg C ha^{-1} for grey-brown podzolics and podzols, respectively. Smith et al. (2006) used a cut-off point of 200 Mg C ha^{-1} to differentiate between organic and mineral soils in parameterising the Rothamsted Carbon Model (RothC; Coleman and Jenkinson 1996). Estimation of C stocks in mineral soils, to a specified depth, is typically done via stratified sampling of SOC content (%), bulk density (BD) (g cm^{-3}) and coarse fragments (such as stones and roots) mass and volume (Olsson et al. 2009, Wellock et al. 2011) Forest soil sampling methodologies for national SOC inventories vary. They include repeat standardised sampling of stock changes, which is rare (Ortiz et al. 2011): paired plots, e.g. forested and non-forested sites on similar soils (Wellock et al. 2011, Lawrence et al. 2013): and chronosequence-based studies (Reidy and Bolger 2013). These methodologies are designed to measure the net effect that temporal and spatial variables, along with climate differences and land management, have on soil C stocks within a site, region or country at a point in time. They are also intended to help forecast the impact of future land-use change (Turner and Lambert, 2000, Scott et al. 2002).

While soils are generally classified as organic or mineral soils, there is also an intermediate group of soils in the continuum (Duffy et al. 2014) of the above mentioned SOC stock ranges. These soils are listed variously in the literature as peaty, peat-topped, humus-mineral or organo-mineral soils (Duffy et al. 2014, Montanarella et al. 2006, Smith et al. 2007). These peaty mineral soils, which the EPA classify as having an organic surface layer <30 cm deep, account for over 21,000 ha of the Irish forest estate (~14%, excluding open areas) (Duffy et al. 2014). They are not as well accounted for when it comes to C stock values and sampling methodology best practice, partially due to the significant site-level spatial variability of surface organic layer thickness (Kiely et al. 2009). In their study of Irish SOC dynamics over the years 1851–2000, Eaton et al. (2008) highlighted the differences between Irish forested mineral and peat soils and the blurred distinction of soil types presented by peaty soils. They also noted that because of the prevalence of peaty soils, such as peaty podzols, Ireland's forest soils run counter to the global trends found in the study done by Guo and Gifford (2002) in that they contain greater C stocks than grasslands. They therefore warranted a focus on further disaggregation of soil classification beyond just mineral and peat soils.

Podzols and peaty podzols

The term podzol comes from the Russian words *pod* and *zola* meaning under and ash, respectively (IUSS 2014). Podzols are primarily conditioned by percolating rainwater in a temperate climate and have soil horizon profiles heavily influenced by iron (Fe) and/or aluminium (Al) chemistry (FAO 2001). In Ireland, podzols occupy an estimated 559,600 ha (8%) of the land area (Gardiner and Radford 1980, Tomlinson 2005), account for 10% of the forest estate (NFI 2013) and are most often located in hilly and mountainous areas at elevations 150 m above mean sea level (AMSL) where rainfall plays a significant part in their development (Finch and Ryan 1966). Due to their topographical location and associated issues of accessibility they are generally found under natural or semi-natural vegetation and their land-use has often been confined to rough grazing or coniferous forest plantations (Finch and Ryan 1966).

The recently developed Irish Soil Information System (SIS) identifies and describes Irish soil types. It uses soils data and a unique blend of current and traditional methods to produce a new Irish soil classification system (Creamer et al. 2014). In the Irish SIS, soil types are identified primarily by 11 soil "Great Groups", one of which is the podzol group of mineral soils. The Podzol Great Group in turn contains subgroups, e.g. "typical podzol" or "humic podzol", which further classifies together soils that share similar characteristics, which is a necessary aid to understanding the complexity of Ireland's heterogeneous soils (Creamer et al. 2014). Within the Irish SIS typical- and humic-podzol subgroups there are several soils described which have a surface peaty horizon (<40 cm-thick), underlying less decomposed organic horizons and overlying mineral horizons (Creamer et al. 2014). To keep the focus on their SOC content (%), this study uses the term "peaty podzol" when discussing these soils. They are found predominantly in mountain and hill terrain in Ireland (Gardiner and Radford 1980) and often at elevations just below upland blanket peat.

Soil C stocks in forest plantations have been a central theme of forest research in recent decades (Byrne et al. 2015). This has addressed a range of issues such as modelling the effects of land use management, changes on the SOC pool (Black et al. 2014) and estimating C stocks in Sitka spruce (*Picea sitchensis* (Bong.) Carr.) plantations (Reidy and Bolger 2013). In addition, several studies have assessed the C stock in prominent Irish forest soil types, e.g. peat soils and gleys (Tomlinson 2005, Byrne and Milne 2006, Black et al. 2009, Wellock et al. 2011). The objectives of this study were to measure BD and SOC content in afforested podzols with the aim of improving baseline mineral soil C stock estimates for Irish forests. As a result of sampling these soils, the need to disaggregate podzols (see Figure 1) and peaty podzols and the respective methodologies employed when undertaking soil C inventories of them needs to be discussed.

Methods and materials

The study sites were selected from the Irish National Forest Inventory (NFI) population of 1,827 sites, which were systematically surveyed between 2010 and 2012 (NFI 2013). The 188 sites in the NFI with a "Group Soil" classification of podzol had a sub-classification, i.e. "Principle Soil", of either podzol (37%) or peaty podzol (63%). All sites chosen for sampling were first rotation Sitka spruce stands, greater than 20 years old with a soil depth >40 cm all located in the Munster region. Following inspection of 12 sites to confirm the presence of podzol characteristics seven sites, three podzols and four peaty podzols (which approximately reflected the NFI "Principle Soil" percentage split) were selected for soil sampling (Table 1). During the site inspections four of the NFI sites were deemed unsuitable due to clear-felling, fire damage, or the presence of a dense understorey of *Rhododendron* and alternate sites were found in the general vicinity which met the selection criteria. The stand age of the alternate sites was provided by Coillte based on Global Positioning System (GPS) coordinates. The sampled sites were located in mountain or hill topographies (between latitude 52° 2' and 52° 48' N and longitude 7° 54' and 8° 51' W) at elevations between 145 and 388 m AMSL.

The soil BD and SOC% was measured starting just below the loose litter layer (L horizon) in 10 cm increments, including F, H, O organic and mineral horizons down to 40 cm, which is in line with the Teagasc test depth for organic versus mineral soils (Creamer et al. 2014). Soil augering was carried out at each site to confirm the presence of podzol soil profiles. At each site a pit of approximately 1.0 × 0.8 m was excavated to a depth of at least 40 cm. Bulk density samples were taken from three of the four pit faces using stainless steel rings with a volume of 100 cm^3 (Eijkelkamp Agrisearch Equipment BV, Netherlands). Four BD samples were taken from the centre of each 10 cm increment below the loose litter layer to 40 cm depth, giving three samples

Table 1: *General features of the podzol and peaty podzol study sites.*

Site name	**NFI / Altrn.**[a]	**Plantation age** (years)	**Elevation** (m)	**Slope** (°)	**Podzol / peaty podzol**	**Irish SIS soil type**	**Organic horizon depth** (cm)
Vee Gap	Altrn.	19	174	18	Podzol	Typical-Podzol	7
Boggeragh	NFI	21	296	15	Podzol	Typical-Podzol	7
Skeheen	Altrn.	26	294	9	Podzol	Typical-Podzol	5
Devil's Bit	Altrn.	23	339	20	Peaty podzol	Typical-Podzol	10
Glenanair	Altrn.	33	248	11	Peaty podzol	Humic-Podzol	16
Anglesborough	NFI	40	451	26	Peaty podzol	Typical-Podzol	13
Keale	NFI	44	263	11	Peaty podzol	Humic-Podzol	10

[a] Altrn: Alternative site because NFI site could not be used.

for each depth from each pit. At two points, 25 and 50 cm from the centre of each of the four pit sides, soil samples were taken to 40 cm depth using a Dutch soil auger (Eijkelkamp Agrisearch Equipment BV, Netherlands). At each site the soil profile horizons were identified using the Irish SIS horizon definitions (Simo et al. 2014), their depth and thickness measured and the stone and root size and abundance was estimated (Tables 2 and 3). At two sites, Vee Gap and Glenanair, adjacent road cuttings allowed exploration of the soil profile below 40 cm.

In the laboratory all soil samples were air dried at room-temperature for at least one week before being oven dried for 24 hours at 105 °C. The dried soil BD samples were weighed and their mass (to ±0.01 g) recorded. The samples where then broken up manually and any visible coarse fragments (i.e. >2 mm)

Table 2: *Soil profile description for podzol sampling sites.*

Site / Horizon	Thickness (cm)	Rock abundance[a] (Code: %)	Rock size class[b] (Code: mm)	Root abundance[a] (Code)	Root size class[c] (Code: mm)
Vee Gap					
L	4-0	N: 0		N	
F	0-3	V: 0-2	F: 2-6	M	FM: 0.5-5
H	3-7	F: 2-5	FM: 2-20	M	MC: 2->5
Ah	7-13	F: 2-5	FM: 2-20	M	MC: 2->5
E	13-70	C: 5-15	CS: 20-200	V	F: 0.5-2
Bf	70-72	N: 0		N	
Bs	72+	C: 5-15	CS: 20-200	N	
Boggeragh					
L	2-0	N: 0		N	
F	0-4	V: 0-2	FM: 2-20	C	MC: 2->5
H	4-7	V: 0-2	FM: 2-20	C	MC: 2->5
Ah	7-14	V: 0-2	FM: 2-20	M	FM: 0.5-5
EA	14-23	V: 0-2	C: 20-60	F	FM: 0.5-5
EB	23+	C: 5-15	CS: 20-200	V	F: 0.5-2
Skeheen					
L	3-0	N: 0		N	
F	0-3	V: 0-2	FM: 2-20	M	FM: 0.5-5
H	3-5	V: 0-2	FM: 2-20	M	FM: 0.5-5
Ah	5-9	V: 0-2	FM: 2-20	C	FM: 0.5-5
AE	9-22	C: 5-15	CS: 20-200	F	F: 0.5-2
Bs	22+	C: 5-15	CS: 20-200	N	

[a] Rock/root abundance codes: N: None, V: Very Few, F: Few, C: Common, M: Many.
[b] Rock size class codes and combinations: F: Fine gravel, M: Medium gravel, C: Coarse gravel, S: Stones, FM: Fine and medium gravel, CS: Coarse gravel and stones.
[c] Root size class codes: F: Fine, FM: Fine and medium, MC: Medium and coarse.
([a,b,c] Source: FAO 2006.)

Table 3: *Soil profile description for peaty podzol sampling sites.*

Site / Horizon	Thickness (cm)	Rock abundance[a] (Code: %)	Rock size class[b] (Code: mm)	Root abundance (Code)	Root size class[c] (Code: mm)
Devil's Bit					
L	2-0	N: 0		N	
F	0-3	V: 0-2	FM: 2-20	F	M: 2-5
Oh	3-10	V: 0-2	FM: 2-20	V	FM: 0.5-5
Ah	10-14	F: 2-5	FM: 2-20	F	M: 2-5
E/B	14-30	C: 5-15	C: 20-60	F	M: 2-5
Bs	30+	M: 15-40	CS: 20-200	F	M: 2-5
Glenanair					
L	4-0	N: 0		N	
F	0-4	V: 0-2	FM: 2-20	M	FM: 0.5-5
Oh	4-16	V: 0-2	FM: 2-20	M	FM: 0.5-5
Ah	16-23	V: 0-2	FM: 2-20	C	F: 0.5-2
E/A	23-50	F: 2-5	FM: 2-20	V	FM: 0.5-5
Bh	50-55	V: 0-2	FM: 2-20	V	F: 0.5-2
Bs	55-70	C: 5-15	C: 20-60	N	
C	70+	M: 15-40	CS: 20-200	N	
Anglesborough					
L	4-0	N: 0		N	
F	0-4	V: 0-2	FM: 2-20	C	FM: 0.5-5
Oh	4-13	V: 0-2	FM: 2-20	C	F: 0.5-2
A/E	13-26	M: 15-40	CS: 20-200	V	F: 0.5-2
Bs	26+	M: 15-40	CS: 20-200	V	F: 0.5-2
Keale					
L	2-0	N: 0		N	
F	0-8	V: 0-2	FM: 2-20	F	FM: 0.5-5
Of	8-10	V: 0-2	FM: 2-20	V	FM: 0.5-5
A/E	10-15	V: 0-2	FM: 2-20	V	MC: 2->5
Bh	15-18	F: 2-5	CS: 20-200	V	F: 0.5-2
Bs	18+	F: 2-5	CS: 20-200	N	

[a] Rock/root abundance codes: N: None, V: Very Few, F: Few, C: Common, M: Many.
[b] Rock size class codes and combinations: F: Fine gravel, M: Medium gravel, C: Coarse gravel, S: Stones, FM: Fine and medium gravel, CS: Coarse gravel and stones.
[c] Root size class codes: F: Fine, FM: Fine and medium, MC: Medium and coarse.
([a,b,c] Source: FAO 2006.)

such as gravel, stone, or roots, were removed. The samples were then sieved through a 2 mm sieve to separate the fine and coarse fractions. The mass of both the fine and coarse fraction was recorded. The volume of the coarse fraction was determined by the water displacement method. The BD of the fine earth fraction (BD_{Pfe}) of each sample was determined using the following formula from Throop et al. (2012):

$$BDPfe = \frac{Mass_{soil} - Mass_{cf}}{Volume_{soil} - Volume_{cf}} \quad (1)$$

where:

$Mass_{soil}$ = mass of oven-dried BD soil sample
$Mass_{cf}$ = mass of coarse fragments
$Volume_{soil}$ = volume of BD ring (i.e. 100 cm^3)
$Volume_{cf}$ = volume occupied by the coarse fragments

Following drying the augured SOC samples were sieved to separate the fine (<2 mm) and coarse fractions. The SOC content (%) of 5.00-5.10 g of each sample was determined by the loss-on-ignition (LOI) method, by placing it in a muffle furnace for three hours at 550 °C and using 0.58 as the generally accepted C fraction of SOM (Guo and Gifford 2002, De Vos et al. 2005). The soil C stock in Mg C ha^{-1} was then calculated according to the following equation:

$$SCS = BD \times SOC \times Depth \times 100 \quad (2)$$

where:

SCS = soil C stock (Mg C ha^{-1})
BD = soil bulk density (g cm^{-3})
SOC = soil organic carbon (%)
Depth = depth to which BD and SOC samples were taken (cm)

Figure 1: *Exposed profiles of a podzol at (a) the Vee Gap site and peaty podzols at (b) Keale and (c) Anglesborough sites.*

Results

The mean BD values (Table 4) for the forest podzols increased from 0.68 in the top 10 cm to 1.04 g cm^{-3} at 20–30 cm, but fell to 0.89 g cm^{-3} in the 30–40 cm soil depth. The Vee Gap soil had the highest mean BD (0–40 cm) of 1.16 g cm^{-3}, while Skeheen one had the lowest mean BD for the same depth of 0.54 g cm^{-3}. The mean SOC % decreased at each 10 cm depth from 0–40 cm at the podzol sites, from a high value of 7.8% nearest the surface to 3.0% at the deepest level. The incremental decrease in SOC in the top 30 cm was evident for the Vee Gap and Boggeragh sites, followed by a small SOC increase at those sites 30–40 cm depth, with an overall decline in SOC of 84% and 67% respectively between the top and bottom 10 cm sampled depths. The Skeheen site had the most homogenous SOC content throughout the 0–40 cm profile with a decline of 30%. There was a moderate SOC increase in the 20–30 cm layer of the Skeheen site in comparison to the over and underlying depth intervals of 11% and 13% respectively. The mean soil C stock (Mg C ha^{-1}) of the podzol sites decreased with each depth increment down to 40 cm, declining by 63% from the top to the bottom 10 cm sampled depth.

The mean BD values for the peaty podzols increased from 0.41 to 0.63 g cm^{-3} with each 10 cm increase in depth through 0–30 cm, but fell at 30–40 cm to 0.58 g cm^{-3}. The site with the lowest mean BD value (0–40 cm) of 0.51 g cm^{-3} was Anglesborough, while Glenanair had the highest mean BD at 0.60 g cm^{-3} for the full 0–40 cm depth. The mean SOC % for the peaty podzol sites also decreased with each 10 cm depth interval down to 40 cm. There was an incremental decrease in SOC% in the top 30 cm for all four sites, but two sites, Devil's Bit and Keale, showed a small increase in the 30–40 cm soil layer. The mean SOC % decreased at each depth from 0–40 cm at the peaty podzol sites, from a high value of 32% to 6% at the lowest depth. The mean soil C stock in the peaty podzol sites also decreased with each 10 cm depth interval down to the 30–40 cm level. The total soil C stock (0–40 cm) also increased by 68% across the sites from a low of 229 to a high of 385 Mg C ha^{-1}.

Discussion

The seven podzol and peaty podzols sites sampled in this study adhered to the soil classification used by Teagasc (Creamer et al. 2014) and the criteria used by the annual EPA "National Inventory Report" on GHG emissions (Duffy et al. 2014). Distinct differences were found in mean BD, SOC% and soil C stock values between podzols and peaty podzols across the four depths sampled. Even with their low mean BD of 0.55 g cm^{-3}, the C rich surface horizons of the peaty podzols had mean soil C stocks (0-40 cm depth) that are over twice that in the podzols, i.e. an estimated 304 Mg C ha^{-1} in the former versus 132 Mg C ha^{-1} in the latter. The mean BD (0-40 cm) for the podzol sites of 0.87 g cm^{-3} was 58% higher than the respective value for the peaty

Table 4: *Characteristics of the podzol and peaty podzol soils sampled. Descriptions included mean bulk density (BD), soil organic carbon (SOC), and soil carbon stock (SCS), by site code and by depth. Also mean BD and SOC for 0–40 cm, and sum of soil carbon stock for 0-40 cm.*

BD *(g cm⁻³)*	**Podzol sites**[a]							**Peaty podzol sites**[b]							
Depth (cm)	VGP	BGH	SKE	Mean BD	S.E.	S.D.	C.V.	DVB	GLN	ANG	KEA	Mean BD	S.E.	S.D.	C.V.
0–10	0.57	0.79	0.68	0.68	0.07	0.20	86.1	0.34	0.31	0.42	0.57	0.41	0.05	0.16	97.2
10–20	1.07	1.00	0.59	0.89	0.08	0.25	88.6	0.65	0.33	0.64	0.77	0.60	0.06	0.21	93.3
20–30	1.48	1.08	0.58	1.04	0.14	0.43	96.9	0.66	0.81	0.46	0.58	0.63	0.06	0.19	135.6
30–40	1.51	0.81	0.34	0.89	0.17	0.52	109.0	0.53	0.96	0.51	0.32	0.58	0.07	0.25	114.1
Mean: 0–40	1.16	0.92	0.54	0.87				0.54	0.60	0.51	0.56	0.55			
SOC (%)	**Mean SOC**							**Mean SOC**							
0–10	8.64	6.99	7.70	7.78	0.53	2.59	33.3	31.8	39.5	35.5	22.3	32.3	1.57	8.88	27.5
10–20	3.51	3.53	5.54	4.19	0.46	2.26	53.9	8.33	39.2	19.6	7.24	18.6	2.67	15.1	81.1
20–30	1.35	1.91	6.24	3.16	0.54	2.66	84.0	5.46	11.3	9.13	6.13	8.01	1.06	5.99	74.7
30–40	1.42	2.31	5.36	3.03	0.39	1.93	63.7	5.50	4.24	7.84	7.46	6.26	0.59	3.33	53.1
Mean: 0–40	3.73	3.68	6.21	4.54	0.48	2.36	58.7	12.8	23.6	18.0	10.8	16.3	1.47	8.32	59.1
SCS *(Mg ha⁻¹)*	**Mean SCS**							**Mean SCS**							
0–10	49.58	55.14	52.07	52.26				109.6	122.5	150.7	127.5	127.6			
10–20	37.55	35.33	32.56	35.15				53.90	130.0	125.4	55.51	91.20			
20–30	19.93	20.58	35.91	25.47				35.91	92.12	42.28	35.36	51.42			
30–40	21.46	18.80	18.06	19.44				29.13	40.72	39.88	24.21	33.49			
Sum: 0–40	128.5	129.8	138.6	132.3				228.5	385.4	358.2	242.6	303.7			

[a] VGP: Vee Gap, BGH: Boggeragh, SKE: Skeheen.
[b] DVB: Devil's Bit, GLN: Glenanair, ANG: Anglesborough, KEA: Keale. S.E.: standard error, S.D.: standard deviation, C.V.: coefficient of variation.

podzols sites. There are very few published sources with BD data by depth for Irish forested soils making direct comparisons with the soil types in this study impossible, therefore only comparisons with other forested mineral soils can be reported. This study's mean BD for 0-30 and 0-40 cm for the podzol sites was the same: both were 0.87 g cm^{-3}. These mean BD values are 7% lower in comparison to the mean BD (0-30 cm) of 0.94 g cm^{-3} for all 21 forested mineral soil sites assessed by Wellock et al. (2011) and 14% lower than the 1.01 g cm^{-3} for the five coniferous forest sites on surface-water gley soils studied by Black et al. (2009).

In their study of mainly humo-ferric podzol forest soils in Canada, with their typically low density organic layers, high root abundance and stony mineral layers, Perie and Ouimet (2008) found that BD was closely correlated with SOM content (r^2 =0.81). The peaty podzol sites in this study had a mean BD value (0-40 cm) of 0.55 g cm^{-3}, 37% lower than the respective value for the podzol sites, which as shown above is already low compared to other forest mineral soils. Given the direct relationship in this study between SOM and SOC content via the 0.58 conversion factor, the high estimated SOC % found in the peaty podzols at each sampled depth helps explain the low BD values found in this study. Without full soil particle and porosity analysis and more extensive measurement of the in-situ coarse fragments it is difficult to accurately assign causality for their low mean BD values. It is thought that the low BD values are attributable to a combination of the thick organic layers in the top 20 cm and the often weakly aggregated sandy texture of podzols (FAO 2001).

The coefficient of variation (CV) values of the SOC % indicates that these soils were highly heterogeneous across all sampled depths, with the podzol sites CVs ranging from 33.3 (0-10 cm) to 84.0 (20-30 cm), with a similar range of 27.5 (0-10 cm) and 81.1 (10-20 cm) in the peaty podzol sites. There was a 65% increase in the soil C stock value between the highest value for the podzol sites and the lowest value for the Peaty podzol sites, i.e. 139 Mg C ha^{-1} and 229 Mg C ha^{-1} respectively. At each sampled 10 cm depth down to 30 cm, the mean soil C stock of the peaty podzols exceeded that of the podzols by more than double. It was only in the lowest sampling depth, 30-40 cm, that this trend changed and difference between the two soil C stock values was 58%. When the combined mean soil C stock for the three podzol sites in this study are compared to the mean of the four coniferous forest podzol sites of Wellock et al. (2011), inclusive of F/H and mineral horizons to 30 cm for both studies, the results were within 5% of one another. This study estimated the soil C stock for those same horizons and sampling depths to be 113 Mg C ha^{-1}, while Wellock et al (2011) estimated it at 117 Mg C ha^{-1}. The estimated mean C stock for the peaty podzols in this study was 197 Mg C ha^{-1}, a 68% increase over the Wellock et al. (2011) podzol values to the same depth.

The soil C stock (0-40 cm) for the podzol sites ranged between 129 and

139 Mg C ha^{-1}, with a mean of 132 Mg C ha^{-1}. This mean value is 15 Mg C ha^{-1} higher than the mean of 117 Mg C ha^{-1} derived from measurements of four podzol sites sampled by Wellock et al. (2011) (0-30 cm, excluding forest litter). It should be noted that the Wellock et al. SOC values were determined using a C/N elemental analyser, in contrast to the LOI method used in this study, though De Vos et al. (2005) conclude both methods are comparable except in low organic C, non-calcareous soils where the former method is more reliable. The mean soil C stock for the podzol sites decreased from a high of 52 Mg C ha^{-1} in the top 10 cm to a low of 19 Mg C ha^{-1} in the bottom 10 cm of the sampled 40 cm soil profile, reflecting the decreasing SOC % at the same increments. The peaty podzol sites had much higher soil C stock (0-40 cm), ranging from 229 to 385 Mg C ha^{-1}, with a mean of 304 Mg C ha^{-1}. This mean is 11% lower than the 343 Mg C ha^{-1} recorded for podzol soils in the Republic of Ireland, as determined by Tomlinson (2005).

Conclusions

The disparity in the C stocks between afforested podzols and peaty podzols in this work underlines the need to disaggregate these soils and has implications for how they should be treated in soil C inventories to reduce uncertainty associated with soil C stock estimation. With their suitability for conifer plantations it is likely that these soils will be further utilised in any future expansion of the forest estate. In such cases of afforestation there may be potentially adverse implications for the stability of their inherent C stocks, e.g. via increased C emissions due to soil disturbance and drainage. Even if afforestation has only a minimal effect on soil C stocks at the regional or country level, its effect on the global C pool could be significant if large scale conversion of agricultural land to forest plantations continues (Paul et al., 2002). To establish more accurate baseline estimates against which future C stock change can be assessed and facilitate a better understanding of the impact of afforestation on their soil C stocks, the methods employed in measuring their soil C stocks and fluxes need to be adapted. Based on the findings of this study, the cut-off point of 200 Mg C ha^{-1} used by Smith et al. (2006) to differentiate between organic and mineral soils is deemed a useful threshold for determining the most appropriate method for monitoring C stock changes. For example, soil C stock sampling methodologies could be used for soils below the threshold and the development of specific C EFs for soils that are above that level.

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Forest Perspectives

Seeing the woods for the trees: the history of woodlands and wood use revealed from archaeological excavations in the Irish Midlands

Ellen OCarroll[a*] and Fraser J.G. Mitchell[a]

Keywords: *Archaeology, charcoal, pollen, wood usage, woodland change.*

Introduction

Wood has always been a key raw material in the manufacture of furniture, tools, containers and nearly all everyday items (O'Sullivan 1994). Wood and its byproduct charcoal, have been used as fuel for everyday use in Ireland in the past and have been extremely important raw materials both economically and culturally up to recent times. Consequently, the catchment area of woodlands surrounding a settlement were often exploited and managed in the past to provide essential raw materials for a community (Stuijts 2005).

The study described herein aimed to reconstruct past woodland landscapes of the midlands region, as well as the anthropogenic exploitation patterns of these woodlands. Reconstructions were based on the analysis of charcoal and wood samples from archaeological excavations which were dated from the Neolithic period (5,000 years ago) to later Medieval times. Pollen cores sampled from close to the archaeological excavations were also analysed and provided complementary proxy information that helped build a picture of the past woodland history of the midlands.

Study area

The construction of the M6 road improvement scheme, stretching for 64 km from Kinnegad to Athlone across Counties Offaly and Westmeath, provided an opportunity to piece together the origins and species of charcoal remains. Consequently charcoal, pollen and wood from archaeological excavations were used as proxies to reconstruct the vegetation type that existed at that time (Figure 1). Currently the landscape of the area is comprised of generally flat to undulating terrain dominated by an extensive suite of glacial and glaciofluvial depositional landforms (Delaney 1997). The underlying geology of the area is dominated by Carboniferous limestone, which is overlain by

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Figure 1: *Excavation in progress showing the type of landscape the M6 traverses (NRA).*

intermittent glacial features such as moraines and eskers. The area was once part of a low-lying lakeland region that had in the post-glacial period been part of a greater midland lake system (Grogan et al. 2007).

The vegetation is dominated by areas of poor-quality scrub and grassland while the brown-podzolic soils, interspersed with grey gleys, are prone to winter water-logging and flooding. Altitude along the study area varies from 76 m at Kinnegad to 60 m at Athlone.

Archaeological samples and pollen cores

Charcoal (18,000 fragments in total) and wood data (1,000 samples) were obtained from 56 archaeological excavations carried out between 2006 and 2009 in advance of the M6 Kinnegad to Athlone road scheme, as well as from excavations from Neolithic trackway sites at Mount Lucas bog in Co. Offaly (Figures 2a, b and 3). The range of archaeological sites from which the charcoal was extracted included some small–scale Neolithic activity, two Bronze Age settlement sites (Figure 4) and numerous burnt mounds (*fulachta fiadh*) (Figure 1), Iron Age metalworking sites and furnaces (Figure 5), industrial activity in the form of Medieval-dated kilns and Medieval charcoal pits (Figure 6), as well as an early Medieval ringfort (Figure 7). A *fulacht fiadh*, generally dating from the Bronze Age, consists of a horseshoe-shaped mound of burnt stones, a hearth(s) and a trough(s). These sites were used to heat water for a variety of possible purposes. They are also known as ancient cooking places or burnt mounds (Egan 2007). Wood and charcoal identifications from *fulachta fiadh* have been shown to be excellent proxies or indicators of the local vegetation associated with their phase of use (OCarroll 2010). Over 1,000 wood samples were also identified from the Neolithic-dated wooden trackways at Mount Lucas and were used to identify the wood species, helping to cast light on the reasons for selecting wood as a working material and were also used as a basis for environment/woodland re-construction at the time the trackways were built.

The main palaeocological or pollen data used for this study were interpreted from a lake core in Cornaher Lough in Co. Westmeath. Cornaher Lough abuts the new M6 road on its eastern side. Consequently the Cornaher Lough diagram provides closely linked palaeoecological data for comparison with the archaeology and charcoal data and are used for comparative purposes in these discussions.

Methods and materials

During excavation, soil samples for flotation were systematically collected from each excavated feature on the archaeological site. The soil samples ranged in size from 0.1 to 65 L, but were on average 6 L in volume. Charcoal was then extracted from the floated material from the hydrated soil samples. Wood samples from the trackways excavated at Mount Lucas were taken from transects across the width of the site at regular intervals.

Wood and charcoal identifications

Charcoal and wood samples were analysed and identified to determine the species and selected structural function(s) on sites, i.e. post holes, firewood, pyre material and burnt remains of wattle. Specific trees such as *Quercus* spp. (oak) would have been selected and used in cremation at burial rites as well as in charcoal production pits to support metalworking activities (O'Donnell 2007, Kenny 2010). Site functionality could be determined in some cases from the analyses of wood and charcoal.

Each wood taxon has a distinct microstructure and this allows charcoal and wood fragments to be identified to species level under a microscope. When slivers of wood or charcoal are examined in this way the patterns in their microstructure are compared to known species or reference keys to identify the species (Figure 8). Charcoal identifications can be used for environmental reconstruction based on the premise that people probably gathered their fuel and building materials from the local area.

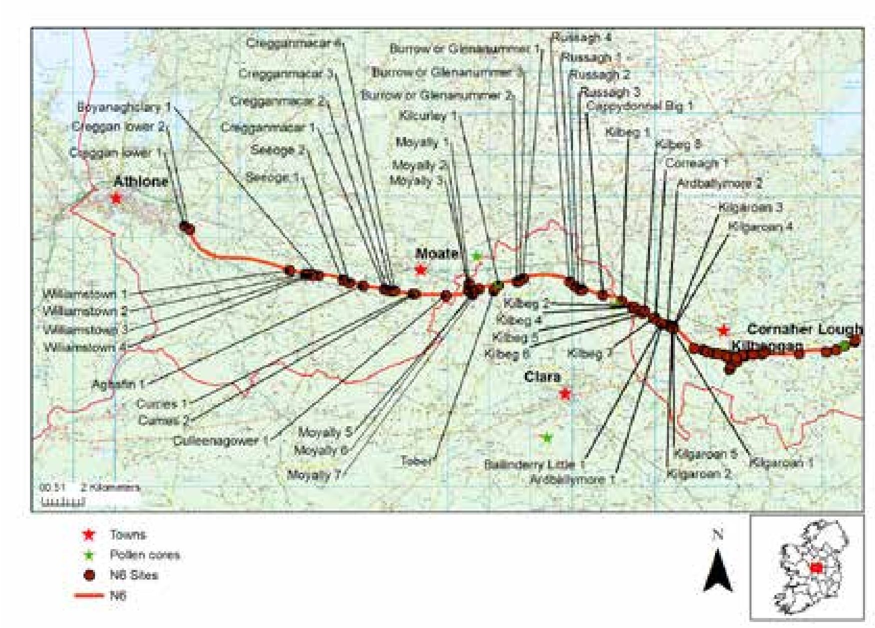


Figure 2 (a): *Map of study area and excavated archaeological sites along the M6 (western portion).*

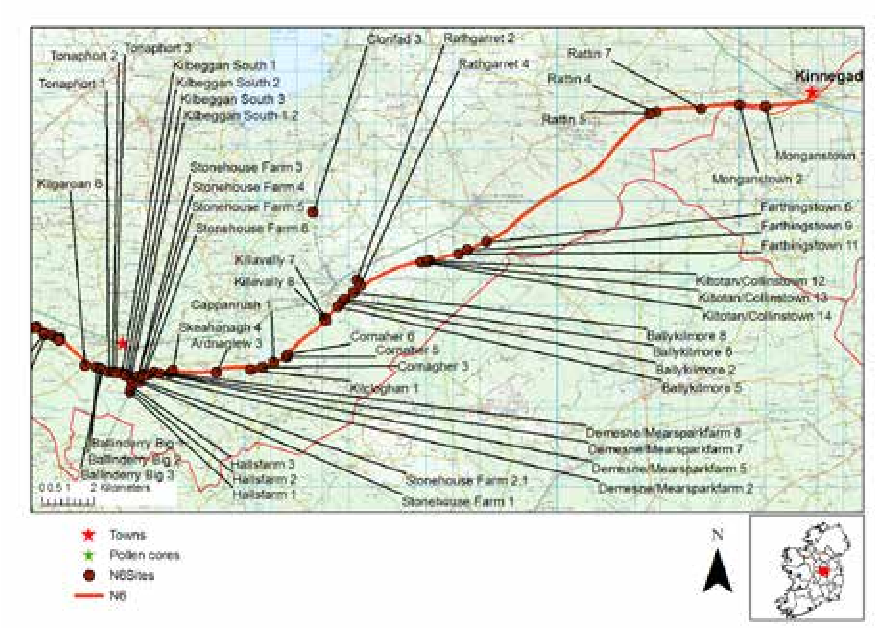


Figure 2 (b): *Study area showing the location of archaeological sites excavated as part of the N6 road scheme (eastern portion).*

Figure 3: *Neolithic trackways under excavation at Mount Lucas, Co. Offaly (photograph by Dominic Delaney).*

Figure 4: *Excavation in progress at the Tober 1 site. This late Bronze Age round house had a large hearth in the centre and post holes can be seen around the exterior (photograph by Fintan Walsh).*

Figure 5: *An early Iron Age furnace at the Moyvalley 2 site*.

Figure 6: *A charcoal pit found in the Curries townland, was dated to the period AD 989–1148*.

Figure 7: *Excavations in progress at Habitation site showing early Medieval Ringfort ditches, Moyally 1 (Photograph curtesy of IAC Ltd. /NRA).*

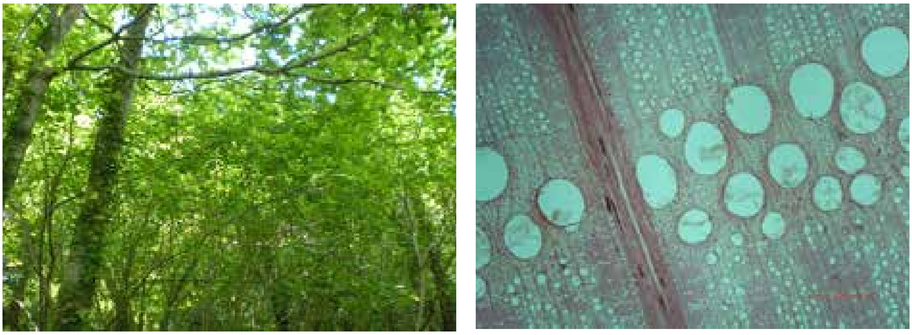


Figure 8: Quercus *trees and wood microstructure*.

Pollen analysis

Most pollen grains are dispersed into the air from vegetation and can accumulate in sediments in lakes, peat bogs and waterlogged ditches, where it builds up sequentially. Sediments can then be extracted for study by coring to obtain a vertical sequence of sediments deposited at particular times. Samples can be taken from a core at 1 cm intervals and examined under a microscope. As the outer surface of a pollen grain or exine is highly durable, pollen can be preserved in sediments for long periods so can be used for identification (Figure 9). Each grain is different in structure and shape, therefore by identifying the amount and variety of pollen grains at each level in the past, the population and types of vegetation that existed in any given area can be reconstructed (Moore et al. 1991). This analysis resulted in the creation of a pollen diagram, which is a graphical expression of the frequency of the different types of pollen over time. Radiocarbon dating of organic samples from the core was then used to provide a chronological framework for these data (Figure 12).

Results

Charcoal and wood

Figure 10a shows the results for the identification of the charcoal species type by time period while Figure 10b presents charcoal results by site/feature type associated with each archaeological site sampled. For comparative purposes, the archaeological sites from the M6 development were reclassified into five types based on function and date: *fulacht fiadh*, industrial (i.e. charcoal production pits, furnaces, metalworking activities and kilns), burial, occupation/habitation and pit types (Table 1). Figure 11 presents the results of wood identifications from the Neolithic trackways analysed from Mount Lucas bog, Co. Offaly.

Figure 9: *Pollen grains from alder (*Alnus glutinosa *(L.) Gaertn.; 25 µm diameter).*

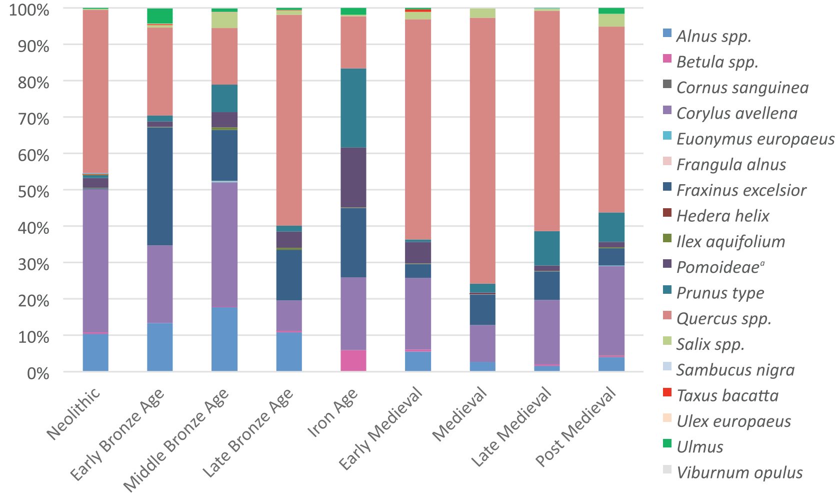
Table 1: *Charcoal and wood samples (and their associated time periods) were excavated from sites along the M6 Kinnegad to Athlone stretch of dual carriageway.*

Site type	Number of samples	Time period
Fulachta fiadh	3	Neolithic
Fulachta fiadh	10	Neolithic/Bronze Age
Fulachta fiadh	19	Early Bronze Age
Fulachta fiadh	29	Early/Middle Bronze
Fulachta fiadh	43	Middle Bronze Age
Fulachta fiadh	21	Middle/Late Bronze Age
Fulachta fiadh	24	Late Bronze Age
Fulachta fiadh	2	Late Bronze Age/Iron Age
Industrial	2	Early Bronze Age
Industrial	1	Iron Age
Industrial	40	Early Medieval
Industrial	13	Medieval
Industrial	7	Late Medieval
Multi – function	7	Multi-period
Multi – function	8	Multi-period
Habitation site	19	Early Medieval
Habitation site	114	Late Bronze Age
Habitation site	108	Multi-period
Pit	2	Late Bronze Age
Pit	2	Neolithic
Pit	1	Post Medieval
Trackway – wood samples	1,000	Neolithic
Total	1,475	

Pollen

The pollen diagram from Cornaher Lough is essentially a series of side-by-side graphs (Figure 12). The x-axis shows the percentage of pollen types associated with a certain taxa at a given period in time. The graph's y-axis shows the depth of the sample, which corresponds to time, with the deepest and oldest deposits usually coming from the bottom of the core samples and the most shallow or recent deposits from the top. The total for all trees and shrubs (Figure 12, far right) provides a summary of the occurrence of these woodland types during any given time over the past 8,000 years.

(a)



(b)

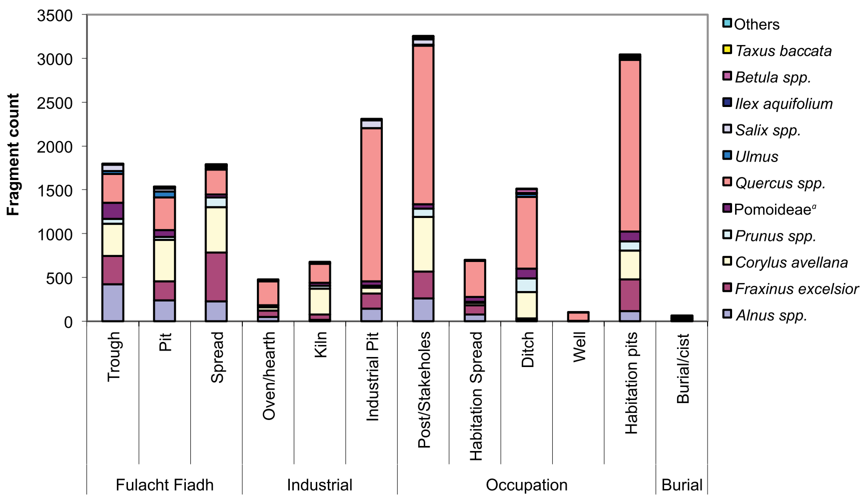


Figure 10: *Woody species identifications (a) per period and (b) by archaeological site/feature type (percentage frequency, n = 1,809) based on data from charcoal and wood samples excavated.*

[a] *Pomoideae includes apple* (Malus)*, pear* (Pyrus)*, hawthorn* (Crataegus) *and mountain ash* (Sorbus)*. It is impossible to distinguish these wood species anatomically*

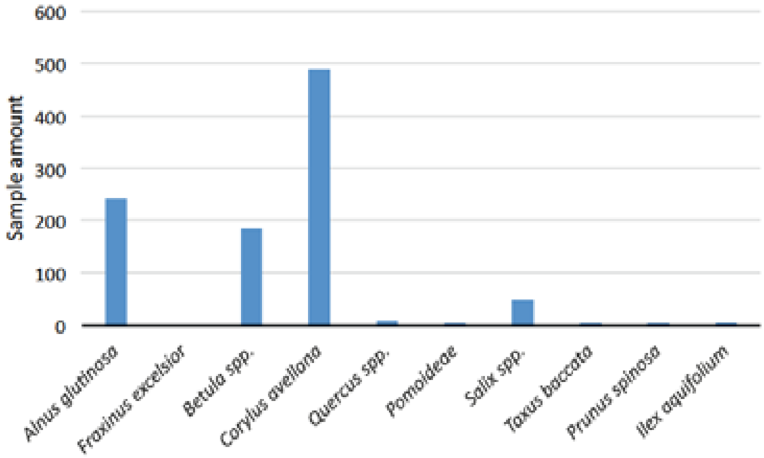


Figure 11: *Total wood identifications (n = 1,000) from the trackways at Mount Lucas which were dated to the Neolithic period.*

A changing landscape – evidence from archaeological charcoal and wood studies

With the exception of the *Ulmus* (elm) decline around 5,840 years ago and the decrease in *Pinus* (pine) cover that occurred about 4,000 years ago, there has been little change in the range of tree species growing on the island of Ireland (Hall 2011). Invariably woodland composition changed apace with anthropogenic activities, as well as being influenced by environmental factors such as climate and soil types. These changes can be traced through the study of both charcoal and the identification of wood and pollen associated with archaeological excavations, as discussed below.

Mesolithic 8,000-4,000 BC (c. 10,000-6,000 cal. BP[1])

There was little evidence for human occupation and woodland depletion during the Mesolithic period along the M6 route apart from a flint flake uncovered and attributed to the late Mesolithic and early Neolithic populations of the area near Rochfordbridge in Co. Westmeath (Egan 2007). Pollen evidence from the Mesolithic period in the midlands shows the development of large canopy-forming trees, such as *Quercus* and *Ulmus* spp. and towards the end of the Mesolithic period the study area would have been dominated by a dense canopy of these and *Corylus avellana* L. cover (Figure 12). *Betula* spp, which had previously been the main constituent of the woodlands in the midlands, declined dramatically once other trees with thicker canopies established themselves (Hall 2011). *Pinus* was also a component of this woodland but was more prolific in the peatland areas than in areas of mineral soils, as shown by pollen sources from lakes and bogs (Heery 1998, Connolly 1999).

[1] The cal prefix shows that the dates result from radiocarbon calibration determination from tree ring data and indicate the number of years before present (BP).

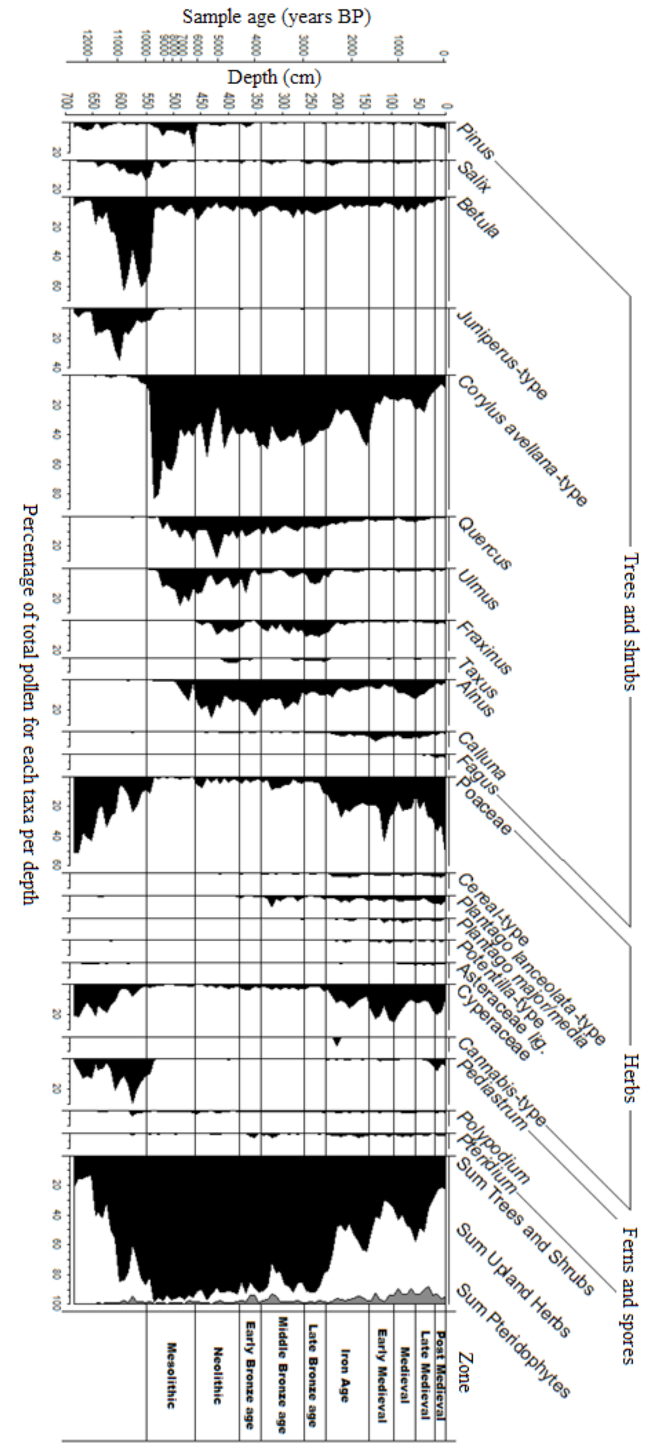


Figure 12: *Cornaher pollen percentage diagram (redrawn with data from Heery 1998) showing selected taxa.*

Neolithic 4,000-2,400 BC (c. 6,000-4,400 cal. BP)

The amount of archaeological data collected in the area during the Neolithic period was also scarce, thus providing limited evidence about tree cover during this period. The dense woodland cover of *C. avellana*, *Quercus*, *Ulmus* and *Pinus* spp., as evidenced in the pollen diagram (Figure 12), coupled with the presence of a large lake system and thin, poorly drained soils, may all have contributed to a dearth in human populations during the Neolithic period. The area was obviously unattractive to the earliest farmers when compared with the western seaboard areas around the Ceide fields in Mayo (Verrill and Tipping 2010), areas of Sligo (Danaher 2007) and Tullahedy in Co. Tipperary (OCarroll 2011). Neolithic remains in the study area comprised of enigmatic pits and trackways at Derrygreenagh and Mount Lucas bogs (Figure 3) in Co. Offaly. Charcoal identifications from the archaeological excavations indicated that woodlands exploited in the area included *C. avellana* and *Quercus* spp., while the low occurrence of *Fraxinus excelsior* L. (common ash) is noteworthy and defined Neolithic woodlands as closed woodlands with little open spaces or clearings, as can been seen during the Bronze and Iron Age periods (Figure 10a). Wood identifications from the Neolithic trackways at Mount Lucas show that *Corylus avellana*, *Alnus glutinosa* (L.) Gaertn. and *Betula* spp. were the most common species used in construction (Figure 11). *Alnus glutinosa* and *Betula* spp. are adapted to a wetter growing environment than most of the other species and would have grown in the marginal woodlands in fen areas close to where the trackway sites were constructed (Lipscome and Stokes 2008). Consequently, wood used in the composition of the trackways would never have been carried far from their source area.

Other wood types identified less frequently were *Quercus* spp., *F. excelsior,* Pomoideae (apple, pear, hawthorn and mountain ash), *Ilex aquifolium* L. (common holly) and *Taxus baccata* L. (common yew) which indicate these woodlands existed, possibly further afield in the dryland and upland areas. Primeval woodlands are also shown to have been present, evidence for which is supported by the insect analysis and may have been relatively intact during the Neolithic period in the midlands. Insects identified from the Mount Lucas excavation, such as *Rhyncolus ater* and *Colydium elongatum,* which are now extinct in Ireland, offer a picture of the Neolithic woodland landscape during the time of the construction of these sites. The now extinct beetles suggest the presence of primary or sub-primary forest cover (Rossi 2014[2], Reilly 2005). In particular, their presence in the late Neolithic trackways, at a time when woodland cover clearance was varied but well underway (Cooney 2000), suggests that primary woodland remained an important element of the landscape at this time in Ireland's midlands. Pollen data from Cornaher Lough show a decrease in *C. avellana* woodlands during the period when the trackways at Mount Lucas were in

[2] Unpublished technical report for Dominic Delaney by Julie Rossi on excavations carried out at Mount Lucas Bog, Co. Offaly.

use, indicating some woodland clearance, albeit not wholescale and only in relation to certain species types.

On the basis of the palynological evidence, it was concluded that there were no major Neolithic *Landnam*[3] phases or woodland clearance in the study area. This contrasts sharply with the evidence for widespread woodland clearance in other parts of the country, such as on the western seaboards at the Ceide fields and the southern portions of Ireland (O'Connell and Molloy 2001).

Bronze Age 2,400-500 BC (c. 4,400-2,500 cal. BP)

Archaeological evidence from early and middle Bronze Age material was also sparse and mainly related to *fulachta fiadh* activity along the M6 routeway, corresponding to a low settlement density. One late Bronze Age settlement site was uncovered along the routeway at Tober in Co. Offaly (Figure 4). Plank tracks were also in use throughout the midland peat bogs during the late Bronze Age period (OCarroll and Whitaker 2009). These tracks were invariably constructed from *Quercus* trees (Ibid. 2009).

A wide range of woody taxa was collected as kindling or for firewood use at the *fulachta fiadh* sites, however *C. avellana* was most dominant. *Quercus* spp. occurred more frequently in the late Bronze Age occupation sites at Tober, Co. Offaly and were used as posts and structural features. By comparison, *F. excelsior* was identified in higher amounts in the hearth and pit features at the occupation sites, suggesting the gathering of wood in previously cleared woods where *F. excelsior* may have grown as secondary regenerated woodland. The overall increase in *F. excelsior* wood throughout the whole of the Bronze Age suggests the opening up of the woodland in the midlands. Heightened *F. excelsior* curves often appear in pollen diagrams in the wake of woodland disturbance and this has been shown in many pollen studies throughout Ireland (Stefanini 2008). The higher occurrence of Pomoideae in the later Bronze Age and Iron Age periods possibly reflect cleared woodlands or scrubland nearby. During periods of clearance Pomoideae types are known to colonise cleared areas in a similar fashion to F. excelsior.

The quantities of *Alnus glutinosa* in the charcoal increased from the Neolithic to the middle Bronze Age periods, highlighting a greater link with and selection of woody taxa from a wetter area, particularly in association with *fulachta fiadh* sites. *Fulachta fiadh* were generally located on the interface between dryland and wetland areas.

The pollen records from the area during the early to late Bronze Age periods show a steady, but still small, reduction in arboreal taxa throughout these periods. All profiles show multiple (albeit not synchronous) *Ulmus* declines during these periods,

[3] *Landnám* is an Old Norse word (roughly translated as "land take") which refers to the Viking style of land management practices from the 9th and 10th Centuries AD.

most likely related to small woodland clearance phases. The Cornaher pollen cores also showed a heavy presence of *C. avellana* in the landscape during the Bronze Age periods, which compared well to charcoal results from this study, which demonstrated a consistent use of *C. avellana* at the *fulachta fiadh* sites during the Bronze Age (Figure 12).

Fraxinus excelsior contributed to over 30% of the woodland taxa identified from the charcoal associated with the Bronze Age periods. This compares well to other studies which show that this species replaced certain woodlands cleared by the first farmers (Caseldine and Hatton 1996). Indeed the *F. excelsior* curve in the pollen diagram (Figure 12) is more pronounced from the later Neolithic period through to the late Bronze Age. It was also in these clearings, created by their Neolithic predecessors, that the Bronze Age peoples invariably occupied. *Ulmus* was also present in higher frequencies in the early Bronze Age and almost completely disappeared from the pollen data set by the Iron Age periods. This is recorded from many pollen diagrams from the area (Figure 12).

Quercus spp. wood dominated the charcoal identifications from the late Bronze Age excavations, indicating the high frequency of use of this tree species, which must be attributed to the woodland clearance noted in the pollen diagram in the latter parts of the Bronze and Iron Age periods. Supporting this observation, there was a reduction in *Quercus* spp, *Ulmus* and *C. avellana* pollen at the end of the late Bronze Age (Figure 12). A possible effect this change had on Irish woodlands can be seen in the charcoal graph for the Early Iron Age as well as the pollen data which indicated regenerated woodlands (Figure 12).

Iron Age 500 BC-400 AD (c. 2,500-1,600 cal. BP)

Linked with the palaeoenviromental evidence from the late Bronze Age, arboreal pollen amounts declined to their lowest level (50%) in the pollen cores recorded from the early Iron Age (Figure 12). Early Iron Age furnaces and associated metal working activities were present in the study area. However, pollen evidence indicated the presence of a more aggressive settlement culture and more widespread woodland clearance phases in the early Iron Age periods than that recorded from the archaeological excavations. Is it possible that the consumption of firewood and charcoal in relation to the smithing hearths and associated activities were expressed in the pollen record so virulently? Indeed, the beginnings of a more widespread and dominant metalworking culture may have only begun to occur in the study area during the early Iron Age. The suspicious death and deposition of the bog body known as the Old Croghan Man in the early Iron Age, during a period of woodland clearance associated with social and economic changes, may only be the beginning of an intriguing and unexplored culture (Plunkett et al. 2009). More evidence in relation to the role this culture played in the depletion of the surrounding woodlands is only just emerging. Certainly the extraction of bog iron ore, which is plentiful in the surrounding peat bogs, may have played a role in this emerging Iron Age culture.

A wider array of wood taxa identified from the charcoal dataset during the early Iron Age periods may demonstrate a greater reliance on a more scrub-like environment where the species forming the main woodland canopies had been depleted during the earlier Bronze Age population expansion. Pomoideae types (*Cratageus*, *Malus*, *Pyrus* and *Sorbus acuparia*) are intolerant of shade, and their increased presence in the charcoal record suggests that the woodland became more open in structure (Cunningham 2005). Similarly *Betula* spp., being light pioneering trees, are recorded in their highest numbers within the charcoal data during the Iron Age periods. The Iron Age sites were generally dated to before 0 AD and therefore pre-date the Iron Age lull (AD 1 – 500) where widespread regeneration of woody vegetation took place (Newman et al. 2007). Pollen data from Cornaher Lough in Co. Westmeath, close by to the eastern side of the study area, also shows this change in woodland structure whereby arboreal taxa decrease significantly.

Consistency between the pollen and charcoal results also occurred in the early Iron Age periods where the pollen profile showed a decline in arboreal taxa and increasing indicators of farming during the period 300 BC-20 AD (Heery 1998, Newman et al. 2007). By comparison, there was an increase in *Quercus* spp., *F. excelsior*, *Ulmus* and *C. avellana* cover, in association with a decline in pastoral activities and in the conversion of land to arable farming during 20-500 AD. This period was during the Iron Age Lull or a period in Ireland's history associated with little anthropogenic activity, consistent with the recorded decline in pollen quantities throughout Ireland and the low number of archaeological sites representing this period.

Medieval periods 400 AD – 1,650 AD (c. 1,600 BP – 300 cal. BP)

The Medieval landscapes of the M6 route comprised of a series of important well organised secular settlements interspersed with ecclesiastical centres, all of which were linked by established routeways (Egan 2007). Ringforts were particularly dominant on the northern portion of the study area, located on slightly better soil types. By comparison, castle sites were located at the southern side of the study area close to the poorer peat bog soils.

Reconstructing Ireland's woodland history throughout the Medieval periods in Ireland is more difficult from archaeological charcoal due the increase in industrialisation and the preferential exploitation of certain wood taxa over another. This is clear from Figure 10a, which shows that *Quercus* spp. were identified more frequently from the charcoal taken from archaeological excavations, but its occurrence in the pollen records is low. Various pollen studies throughout Ireland have recorded much lower levels of tree pollen relative to herbaceous pollen, indicating that large-scale destruction of the major woodlands had taken place during the earlier pre-historic periods to provide land for arable and pastoral farming (Mitchell and Ryan 1997). This was also the case in the midlands. Identifications of charcoal by this author indicated that there were nearly equal quantities of *Quercus* spp. from the early to the late Medieval periods, with only minor fluctuations in the quantities of *C. avellana* and *A. glutinosa* charcoal.

Quercus spp. wood was of increasing importance for use in charcoal production pits during the last millennia and may have been managed to support the charcoal industry, with the aim of producing a steady supply of even-sized oak rods. Over 14 areas along the M6 route produced evidence of charcoal production pits. Some were dated to the early Medieval period and others to the Medieval or late Medieval periods. Therefore, their use spans over 1,000 years. *Quercus* spp. charcoal dominated at the majority of the charcoal production pits. *Salix* charcoal was identified in one pit while some pits near Kilbeggan showed a wider variety of other genera in addition to *F. excelsior*, *C. avellena* and Pomoideae, suggesting that this pattern was not consistent across all pits.

A large portion of the identified *Quercus* spp. ranged in age from 5 to 35 years and occurred mainly as brushwood. According to Gale (2003), the best charcoal for iron smelting came from 25-year-old coppiced *Quercus* spp. In England coppicing was practiced by ironworkers to ensure a continuous supply of wood (Armstrong 1978) and it is likely, based on the tree rings counted and the wood species identified from the charcoal pits, that oak wood was being coppiced in Ireland for charcoal requirements in the early Medieval periods.

Similar studies by this author along the N5, Charlestown by-pass in Mayo, have shown that these charcoal pits are most likely related to large scale settlement sites, such as at Lowpark in Mayo (Gillespie and Kerrigan 2010). The high-status crannog site, known as Ballinderry 2 where much precious metalwork was found, is located close to many of the charcoal production pits along the M6 and is likely to have made use of much of the charcoal burnt to support the metalworking activities at the crannog site (Hencken 1936 and 1942).

The Anglo Norman invasion in 1169 heralded the beginnings of a new era in Ireland, coinciding with the initial stages of the Medieval period (1200-1400 AD). The invasion resulted in the foundation of many walled borough towns, castles and churches and an increase in agricultural and commercial activities. Charcoal production pits were still in use, albeit not as frequently and kilns associated with cereal and pulse drying were uncovered and became more frequent along the M6. The use of kilns along the M6 shows that a move towards arable agriculture occurred at this time. *Quercus* spp. and *C. avellana* were the main wood genera associated with these kiln activities, suggesting these woodland types were still in existence and use during this Medieval period.

Indeed, cartographic sources, such as Honer's map of Co. Offaly, show that woodlands were still a prominent feature in the landscape in the 15th and 16th centuries (Honer 2007). These woodlands were most likely in the form of scrub or coppiced *Quercus* spp. and *C. avellana* woodlands. Platforms and wooden structures were being constructed within the bogs from *A. glutinosa*, *C. avellana*, *Betula* spp. and *Salix* spp. These platforms and structures were constructed during the 12th – 16th centuries in the bog areas as part of a tradition of exploitation of the natural flora and fauna (OCarroll 2009). These structures may have been constructed in response to the drop in temperature during the "Little Ice Age" experienced in the 14th – 16th centuries. The increased accessibility afforded by the trackways allowed greater exploitation of wildfowl as a food source and rushes for domestic and constructional uses. Tower houses were also being constructed during the late medieval periods, of which there are many recorded from the study area.

Pollen records show the clearance of woodlands in the early Medieval period (400 – 1200 AD) which continued steadily through the Medieval and late Medieval periods (Figure 12). This period of woodland depletion included substantial loss of hazel scrub due to population expansion and ever increasing demands on the wooded landscape, both commercially and domestically. There was a rise in *C. avellana* cover, as shown by the pollen core data during the late medieval periods, followed by a sharp drop during the post-Medieval period (to present). The rise in *C. avellana* scrub was likely related to a decrease in human activity due to the Black Death, which arrived in Ireland in 1348 and dramatically reduced Ireland's population, particularly in the towns (Kelly 2001). *Quercus spp, Ulmus* and *F. excelsior* never fully recover after the earlier woodland clearances in the late Bronze Age and Iron Age. *Alnus* and *Betula* are present in the landscape in varying amounts during this Medieval period and were shown to be used as construction material for the platform sites uncovered in the peat bogs (Whitaker and OCarroll 2009). Grass pollen increases in response to woodland clearance phases as indicated through the pollen diagram from Cornaher Lough (Figure 12).

Post Medieval c. 1650 to present AD (c. 300 – 60 cal. BP)

Pollen evidence from the post Medieval periods show a dramatic decline in the amount of arboreal cover, most notably by *C. avellana,* coupled with a rise in modern agricultural activities and the export of timbers of such species to Europe and beyond (McCracken 1971). The use of *C. avellana* at the archaeological sites increased. Other charcoal woods present in the archaeological samples were *Quercus* spp. as well as smaller quantities of *F. excelsior*, *A. glutinosa*, *Salix* spp. and *Prunus* types

(Figure 10a). The widespread clearance of woodlands may have occurred during the Plantation period. This decrease in woodland pollen is noted in other cores from the midlands such as at Monaincha, Co. Tipperary (Hall 2003). From the 16th century on, tree clearances accelerated probably because the ruling English Government required timber for building and industrial uses. Consequently, by the 1900s only 1.46% of the land area of Ireland was covered by woodland (OCarroll 1984). *Pinus* and *Fagus* curves, albeit small, occur indicating the introduction of these taxa types into the midland areas during the post Medieval periods.

Conclusions

Charcoal, wood and pollen records from archaeological sites provided essential information, thus allowing the change in the composition of past woodlands over time to be described. Woodland history however, is not the same throughout Ireland.

There was little evidence of occupation along the M6 during the Mesolithic and Neolithic periods. Although few charcoal samples were dated to the Neolithic period, the data indicated woodland cover comprising *Quercus* spp. and *C. avellana* woodland types. *C. avellana,* as well as *Betula* spp. and *A. glutinosa* were mainly used in the construction of the Neolithic trackways. Pollen, wood, charcoal and insect evidence indicated the presence of a dense primary woodland forest during this period. There was no evidence in the pollen proxy records of *Landnam* or woodland clearance phases during the Neolithic periods, although it is recognised that there was a dramatic reduction of arboreal cover during a similar period along the western seaboards of Ireland (O'Connell and Molloy 2001). Bronze Age woodland clearance was also much less visible in the study area when compared with other parts of Ireland (Molloy and O'Connell 2011). However, clearance of primary woodland during the Bronze Age and early Iron Age periods resulted in the growth of secondary woodlands in which *F. excelsior,* Pomoideae and *C. avellana* were common. *C. avellana,* followed by *F. excelsior, Quercus* spp. and *A. glutinosa,* were identified more frequently from the *fulachta fiadh* archeological sites, indicating that these were more abundant in the vicinity of these sites. Due to previous woodland clearance episodes during the Iron Age, charcoal identifications and pollen evidence suggest a more open, varied, wet and scrubbier-type of landscape.

Quercus spp. dominated records from the Medieval periods onwards, which is in part an indicator of arboreal cover, but this may also be related to an increase in the complexity and economic reliance on the wood from certain species, i.e. *Quercus* spp. predominated in charcoal pits and as construction material. The regular even-aged *Quercus* spp. identified from charcoal remains indicated that *Quercus* spp. woods were managed at this time to supply material for use in the charcoal pits. These pits, which were numerous between the 8th and 14th centuries, would have been used to supply and support an emerging metal working industry at the ecclesiastical centers and crannog sites in the midlands areas.

The extensive clearance of woodlands that occurred in the late Bronze Age and early Iron Age along the M6 continued into the Early Medieval periods until by the 1650s there was little forest cover present in the Irish Midlands.

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Delivering renewable energy from our forests

Des O'Toole[a*]

In the current economic climate, Irish businesses cannot afford to ignore the high cost of energy. Most businesses are exposed to the volatile nature of traditional oil-based fossil fuel prices. However, unlike oil or gas, biomass is close to carbon neutral and Coillte is playing a key leadership role in the supply of sustainable biomass energy solutions to Irish industry and business. Coillte provides long term, secure biomass-fuel supply contracts to its clients and assists in the evaluation of both the technical and commercial viability of projects for large-scale energy users.

The Government White Paper on Energy Policy set a target of 12% of thermal energy to come from renewable energy sources by 2020. However, the renewable heat sector remains largely undeveloped, having grown slowly to 5.7% (2013), mainly as a result of wood waste utilisation in the timber processing sector. Based on our current heat from renewable energy sources (RES-H) trajectory, Ireland's 2020 target will not be achieved (Figure 1) with the risk EU fines will be imposed on Ireland.

Under the EU Tracking Roadmap,[1] prepared for the European Commission in 2014, it was noted that Ireland had no programs for the development of certain technologies such as high efficiency combined heat and power (CHP) generating systems or others to more efficiently utilise biomass. One of the recommendations from that report was

Figure 1: *Ireland's progress in obtaining thermal energy from renewable energy sources (RES-H) during the period 1990 to 2013 (Source: SEAI).*

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[1] Source: http://www.keepontrack.eu/contents/publicationseutrackingroadmap/kot_eutrackingroadmap2014.pdf [Accessed July 2015].

to introduce a reliable RES-H strategy with appropriate support schemes. It stated that Ireland was deploying less biomass than planned and that previous support programs had expired and had not been replaced. In response, the Department of Communications, Energy and Natural Resources (DCENR) published a draft Bioenergy Plan[2] in October 2014 that acknowledged a gap in meeting 2020 RES-H target of 200 ktoe[3] and announced the intention to introduce a Renewable Heat Incentive (RHI) in 2016. This demand-led incentive should provide the much needed catalyst to grow the bio-energy sector and the market for biomass in Ireland. An unintended consequence of that announcement has been that the market has stalled due to the uncertainty created. Most interested parties that had been considering biomass as an energy source have postponed project investment decisions until clarity is given on the RHI qualifying criteria and the proposed tariff banding. The Irish BioEnergy Association (IrBEA), the industry body representing the bio-energy sector, has called upon the Minister for Energy to confirm that any eligible renewable energy installations, completed during the period from the date of the announcement to the date that the RHI becomes operational, will benefit from the new support as if the installation had been completed on the date the relevant scheme launches – a so-called "grandfathering" commitment. It would ensure that projects can start the process of planning, negotiating with boiler and fuel suppliers and commence construction secure in the knowledge that they will not be excluded from the scheme. A similar approach was adopted successfully in the UK prior to the launch of its RHI. A further consultation on the RHI was launched at the end of July 2015[4] and the industry concern regarding "grandfathering" is now being considered. Clarification is awaited.

Developing the Bio-Energy Sector

The bio-energy sector reduces energy costs for industry in Ireland, allowing a displacement of expensive fossil fuel to improve competitiveness. Reducing Ireland's reliance on fossil fuel imports, reducing national greenhouse gas emissions and improving domestic fuel security are key pillars for developing a green economy. The bio-energy sector also stimulates rural development and local job creation in the processing and logistics of wood chip and in the design, installation and maintenance of boiler technology. It provides an outlet for our growing private timber resource and a channel to market for growers of energy crops. Stimulating increased demand with the RHI will mobilise our forest resource and allow the establishment of local grower groups who in turn will be able to supply biomass energy to local industry with the economic benefits being shared locally (Figure 2).

[2] Source: http://www.dcenr.gov.ie/energy/sustainable+and+renewable+energy+division/draft+bioenergy+plan.htm [Accessed July 2015].

[3] Kilo-tonnes of oil equivalent.

[4] Source : http://www.dcenr.gov.ie/energy/Lists/Consultations%20Documents/Renewable%20Energy/Renewable%20Heat%20Incentive%20-%20Technology%20Review%20consultation%20-%20final.pdf [Accessed July 2015].

The Biomass Supply Model

Coillte are already at the forefront of mobilising the bio-energy sector. Coillte has established a network of regional hubs to ensure the continued supply of biomass to customers. These long-term biomass supply contracts displace several thousand litres of imported fossil fuel per week by providing more competitive energy costs for the businesses concerned, thereby helping to maintain competiveness and securing local jobs. Coillte plan to establish new hubs as new demand for wood chip arises. Through these regional hubs, wood chip will be supplied to clients in the pharmaceutical, textile, industrial and hotel sectors.

Each regional biomass fuel-supply hub operated by Coillte typically comprises a large 4 to 5 ha secure log-storage yard and covered wood chip fuel-storage sheds (Figure 3). In addition, a weighbridge and a quality testing laboratory in place at each hub. Each hub will have a range of specialist chipping machinery and equipment capable of producing wood chip and access to a range of delivery vehicles for haulage.

Coillte is committed to a strategy that matches renewable energy requirements with local biomass supply. Small diameter pulp logs are sourced through a local Coillte forestry team from both state and private sector sources within a region. These logs are sourced and delivered on a pre-planned basis several months in advance. Logs are systematically stacked for open-air drying to the required moisture contents specific to each customer's boiler requirements. The key to ensuring good quality wood chip at the correct moisture content at each hub is to manage stock rotation and replenishment and to ensure suitable air flow through

Figure 2: *Biomass wood chip production at Coillte's biomass processing hub in Caherciveen, Co. Kerry.*

Figure 3: *Coillte's biomass processing hub in Drumkeen, Co. Donegal. Image shows the level of log storage required to ensure sufficient volumes of dry chip are available year round to supply the local heat market. Lower Image: The hub at Drumkeen contributes significantly to the local economy.*

the stacks. Stacks are covered during the winter months. Seasonal variations in log moisture need to be anticipated and controlled with great care at each hub. This can only be achieved through experience and by having a strong partnership with supply contractors.

All wood chip is be produced strictly in accordance with quality specifications set out in I.S. CEN/TS 14961: 2005. Wood samples are gathered in pre-approved aluminum sampling trays to determine moisture content using the oven-dry method and/or using pre-approved and calibrated moisture testing devices (Figure 4). Particle size is controlled during the chipping process by the provision of the appropriate size screens on the chipper feed. Regular testing is undertaken to assess the percentage of fine material mixed in with the chips.

Figure 4: *Panel A shows a wood chip auger infeed to an industrial biomass boiler for steam production. Panel B shows part of the routine quality testing procedures employed to ensure the quality parameters of supply lots. Variation in quality parameters (moisture and others) can be high so processing plants rely greatly on the knowledge and experience of contractors to help ensure that a consistently high quality product is supplied.*

Figure 5: *Biomass haulage. Image shows moving floor trailer deliveries to an industrial scale boiler. Trailers typically carry 20 to 24 t and can off-loaded at the client's fuel store in about 15 minutes.*

The wood chip delivery vehicle fleet is comprised of a range of vehicles, from large moving floor trailers (carrying 20 to 24 t loads, see Figure 5) to smaller tipping vehicles with side blowers (8 to 16 t loads) depending on a specific client's fuel handling and on-site storage infrastructure. The biomass loads that are delivered are checked for compliance with moisture content, particle size and percentage fines[5] criteria. Each client is then invoiced per Giga Joule of energy delivered.

Coillte aims to be a producer and supplier of sustainable energy products well into the future (Figure 6).

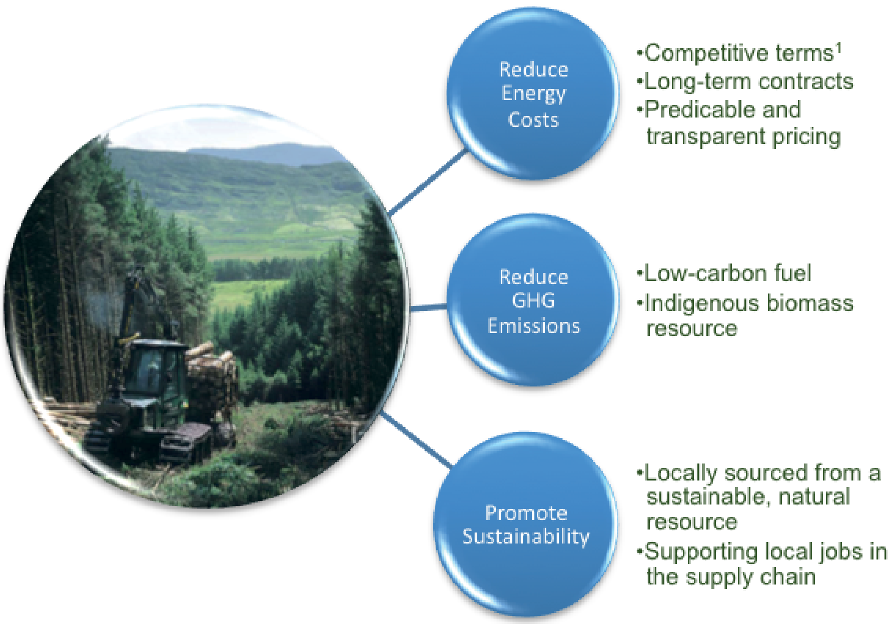

Figure 6: *The three main benefits from Coillte's provision of biomass for renewable energy.*[1] *Competitive terms – Coillte offers long term fuel supply contracts, typically 5- to 7-year terms. Annual price reviews are indexed and linked to 3rd party indices. Clients can make the investment in a boiler system safe in the knowledge that Coillte will provide a long-term commitment to supply material at attractive rates.*

[5] The chip material is screened to the correct size and only a certain proportion of fines/dust is tolerated in the mix. Ideally, a clean chip with very little dust is the most desirable product. The CEN standard has the permitted limits for each chip size.

Doneraile Park

The long St. Leger connection

Seamus Crowley

The arrival of St. Legers in Ireland

When Henry VIII of England decided to suppress the monasteries and break away from the Church of Rome, he gave the job of implementing the process to his "trusty and well beloved servant" Sir Anthony St. Leger of Ulcomb in Kent who was reputed to be "a wise and warie gentleman". Sir Anthony, in his capacity as a member of the Kent Grand Jury, helped to find a "true bill" against Ann Boleyn, which allowed Henry to have her executed in 1536 – a trusty servant indeed!

Having finished the job of suppressing the monasteries in England, Sir Anthony was sent to Ireland to render similar service in 1537. He supervised the dissolution of the monasteries in areas subject to the King's writ and also succeeded in getting the Irish chieftains to accept Henry as King of Ireland. Before that the English King was described as Lord of Ireland, which gave him much less authority. Later Sir Anthony St. Leger was appointed Lord Lieutenant of Ireland and from which time on the St. Legers had a presence in Ireland.

When Sir Anthony St. Leger returned to England, one of his sons, William, who later did not feature in Sir Anthony's will, was "catered for" in Ireland and took part in both government and army. William's son, Sir Antony St. Leger's grandson, Sir Warham St. Leger remained in Ireland until his death in 1600. He died following a single combat engagement with Hugh Maguire of Fermanagh outside the gates of Cork. Hugh Maguire also died in that combat.

Sir Warham's son, William, having killed a man in his youth, had to flee Ireland and spent eight years in the army in the Netherlands during which time he married Gertrude de Vries, a lady from Lower Saxony. He was then pardoned by James I and returned to Ireland with his wife and two sons. In 1627, he was appointed Lord President of Munster, with the title of Sir William St. Leger. His headquarters was in Mallow.

The Synan Clan

In the meantime the Synan family, who first came to Ireland as a body of bowmen with Strongbow's army, had a strong connection with Doneraile and later on with the St. Legers. They first settled in the Shandon area of Cork City but later moved to Kilbolane near Millford in North Cork where their castle can still be seen. Finally they moved to the Doneraile area where they "waxed strong" and built tower houses in

Doneraile and nearby Castlepook and Richardstown. They held their Doneraile lands under the lordship of Lord Roache of Castletownroache.

The Desmond Rebellion and O'Neill's march south

When the Earl of Desmond rebelled in the 1570s, he was joined by the Synans. However their overlord, Lord Roche, remained loyal and did not join in the rebellion. When the dust settled all Desmond lands were forfieted to the crown, but due to the influence of Lord Roche, the Synans did not loose their land and were pardoned. However, the rebellion caused financial ruin for the Synans and in 1593 they partially mortgaged their Donereaile Castle and thirteen and a half ploughlands (a ploughland was a Norman measure based on the area that could be ploughed in a year by eight oxen, believed to be between 120 and 160 acres) to Sir Thomas Norreys of Mallow. The following year, Sir Thomas Norreys and the Synans jointly mortgaged all the property to a Captain Francis Wainman who was from Norreys home country of Rycote in Oxfordshire and was with him in Mallow. Wainman proceeded to establish a large sheep farm in Doneraile. Wool prodution was a very important commercial enterprise in the late 16th century.

In 1599 Hugh O'Neill came south with a strong army to rustle up the support of southern clans for his campaign against the English. They attacked and captured Doneraile Castle and nearby Kilcolman Castle. Edmund Spencer, who was in Kilcolman, took fright and fled with Wainman to England where Wainman died later the same year. The years of war and the O'Neill defeat at Kinsale in 1601 created much confusion in the region. Doneraile was left untended until 1629 when Sir William St. Leger, Lord President of Munster (based in Mallow) was looking to acquire a property suitable for a gentleman of his status.

The St. Leger Purchase

St. Leger found the property he was looking for in the Doneraile lands of the Synans and purchased the mortgage from Captain Wainman's son, Sir Francis Wainman for £1,800 English pounds in 1630. Thus began 340 years of formal ownership of Doneraile by St. Legers, which ended in 1969 when it was purchased by the Irish State. Three years later he purchased another mortgage on four ploughlands from the Spencer estate at Kilcolman, which bounded his Doneraile lands. In 1636 he sought to retrieve Castlepook and two ploughlands around it from the Synans. This property had been already mortgaged by the Synans in 1594 and was part of the mortgage St. Leger had paid for. The Synans thus appear to have been squatting on this land for 36 years. The matter went to court arbitration and St. Leger was deemed "to have the more ancient right" and was given posession. However, he paid the Synans £300 of "good English money in hand", as was recorded on the receipt.

In 1639, to copperfasten his title to the properties he had purchased, he applied for a patent under the surrender and regrant scheme. He was granted this patent known as "The Black Letter Patent of Doneraile" with rights for Fairs, Court Leet (a yearly or half yearly court that the lords of certain manors held to enforce local policing) and Court Baron (similar to a Court Leet except it dealt with more serious offences).

Sir William St. Leger had two sons; his elder son, Sir William St. Leger, died at the battle of Newbury in England fighting for the Royalist cause during the civil war in England and Captain John St. Leger, his younger son, stayed in Ireland. The latter never recieved a title, perhaps because of the St. Legers support for King Charles I during the Cromwellian period. However, he married the daughter of the Earl of Donegal, which would have given him some protection. He did receive a commission as Captain of a foot company in the regiment of the Lord President of Munster in 1647, which was renewed in 1662 after the restoration of Charles II in 1660. He recieved the freedom of Cork in 1666 and Youghal in 1675. In 1679 Charles II issued a renewed Patent to John St. Leger, making Doneraile, formerly a manor with Courts Leet and Baron into a Borough, which allowed Doneraile to elect two members to the Irish Parilament. John St. Leger died in 1696 and was succeeded by his son Arthur.

Arthur brought a large estate in Co. Waterford into St. Leger hands through his marriage to Elizabeth Hayes grand-daughter of John Ottrington, a former Lord Mayor of Dublin. Lewis' Topographical Dictionary (1837) in a referance to Kilmeaden states that a Poer (Power) estate of that area was confiscated by the Cromwellians:

> ...and divided among the soldiers of the Republican army, who transferred their shares to a gentleman named Ottrington. The tomb of this John Ottrington is in the church yard, having been erected by his grand-daughter, Elizabeth, Viscountess Doneraile, through whom the estates were inherited by the present Viscount.

It appears that John Ottrington did not get on with either his daughter or his son-in-law and left all his property to their daughter (and his grand-daughter) Elizabeth. Unknown to his son-in-law, he arranged a secret marriage between Elizabeth and Arthur St. Leger. The "Doneraile Walk" along the cliffs in Tramore, Co. Waterford, reflects to this day the link with the St. Legers. Elizabeth is also buried in her grandfather's tomb in Kilmeaden and the name "Hayes" became a St. Leger christian name for subsequent generations of the family. Her husband, Arthur St. Leger, was created Baron Kilmeaden in 1703 and elevated to 1st Viscount Doneraile (of the 1st creation) a year later.

The Lady Freemason

One of the most enduring stories of Doneraile Court is that of the Lady Freemason. In 1712, eighteen-year-old Elizabeth, daughter of Viscount Doneraile, fell asleep in the library one evening while Lord Doneraile, as he occasionally did, opened a Freemason

Lodge meeting in the room next to the library with his sons and local gentry. The wall between the two rooms was incomplete and when Elizabeth woke up she heard noises next door and peeped through a hole in the wall. She soon got alarmed by what she saw and tried to leave the scene. However, as she went to leave she was caught by the butler who was keeping guard on the lodge room and he brought it to the notice of the meeting. After some discussion as to what to do, it was decided to induct her into the Freemasons on her swearing to secrecy, which she accepted.

Elizabeth's membership of the Mason's was not widely known until 37 years after her death in 1774. In 1811 a London publisher published the story and a mock up image of her in a Mason's apron surrounded by Masonic symbols. The story we have today is based on a family pamphlet issued in 1811, 99 years after her induction into the masonic order. A detailed analysis of the Lady Freemason's story can be seen in Hyland (1985).

Reconstruction of Doneraile Court

The 1st Viscount Arthur, had two sons and one daughter –the Lady Freemason. During his lifetime he commissioned the architect Isaac Rothery to revamp Doneraile Court from a two-story over basement house to a three-story house over basement which is its present facade. The bows at each side and the front porch were later additions (Figure 1). In 1727, Arthur St. Leger died and a map was drawn up by one Hueston, probably in connection with the transfer of the property to his eldest son, another Arthur, the 2nd Viscount. This map called *An Upright prospect of Doneraile,* shows the park as it was at that time and is thus an invaluable record for historians (Figure 2).

The 2nd Viscount was succeeded by his son, Arthur Mohun St. Leger, who became

Figure 1: *South-east view of Doneraile Court.*

the 3rd Viscount in 1734. Arthur Mohun St. Leger died in 1750 and as he had no children, the title of 4th Viscount went to his uncle, Hayes St. Leger, the second son of the 1st Viscount. While the 2nd and 3rd Viscounts did not appear to have lived in Doneraile, the 4th Viscount appears to have always lived in Doneraile Court. Quoting Dr. Charles Smith's history of Cork (1750) about Doneraile:

> ...is one of the most pleasant and beautiful villages in this kingdom, it is almost surrounded by groves of lofty firs, which flourishing at all seasons of the year, render it always agreeable: but this place is indebted for the greater part of its beauty to the fine house and extensive improvements of Hayes St. Leger, Esq...

Hayes was to become the 4th Viscount shortly after this was written. Continuing, Smith mentions the house facade "a fine cascade with resevoirs," and "gardens well laid out and of considerable extent" and in them was "a wilderness and a labyrinth". At the foot of the garden:

> ...is a canal of 370 yards long by 140 yards wide well stocked with fish. The water is constantly supplied by a large wheel that casts up a part of the river Awbeg into a reservoir, which is conveyed underground to the canal... On the other side of the river are pleasant lawns and an extensive deer park, well planted and enclosed to the east of the house is a fine (duck) decoy.

Arthur Young included Doneraile on his tour of Ireland in 1777. He commented on the lawns, woods and cheerful aspect of Doneraile Park. He elaborates on the water wheel, saying it was:

> ...an improvement on the Persian, which raises a regular stream 28 feet; the [stream] which turns it is confined by a double wall to the exact dimension of the boxes which takes in the water and it works constantly and regularly without trouble or expence.

In 1752, the 4th Viscount had an elaborate marble memorial plaque erected in Doneraile church in memory of his father. It was carved by Sir Henry Cheer of London at a cost of £300 and erected on the wall of the church for £14 by the O'Daly stone mason from Shanballymore. It traces the 1st Viscount ancestry back to the illustious Sir Anthony St. Leger "... who was so diligent and faithful to King and Country". It is now a listed item in the Monuments of the Dead in Ireland. The 4th Viscount was praised for his happy marriage and was very attached to his wife. When she died he ordered a wall plaque similar to the one for his father, which is attached to the wall of St. Patricks Cathedral in Dublin.

The origins of Steeple Chasing

In 1752, during the life time of the 4th Vicount, a horse race took place between the Buttevant church and the Doneraile church. Two local gentlemen – O'Callaghan and

Burke –disputed who had the best horse and to settle the matter they raced from "Steeple to Steeple" over a distance of four and a half miles of "stiff country" giving the name Steepechase to the English language. Interestingly, nobody is now quite sure which horse won! A nephew of the 1st Viscount, Major General Anthony St. Leger, who lived in Doncaster, initiated the Doncaster St. Leger horse race in 1776. It is a race over two miles for three-year-olds. Thus the term "Steeple Chase" and "The St. Leger" entered the house-racing vocabulary.

The saga of the priest's horse whipping

The 4th Viscount died in 1767 and having no son, the title died with him. However, the estate was inherited by his nephew –St. Leger Aldworth, son of the Lady Freemason.

Figure 2: *Heuston's 1728 map of Doneraile.*

In order to regain the title he applied to the soverign to change his surname to St. Leger, thus becoming St. Leger St. Leger. He became Baron Doneraile in 1776 and the 1st Viscount Doneraile (of the 2nd creation) in 1785.

He became famous however, for his involvement in a notorious incident. It appears he seduced a local girl and had her installed in Doneraile Court. Her brother also seduced a married woman causing much scandal locally. The parish priest Fr. Neill was ordered by his Bishop to excomunicate the man. The sister complained to Lord Doneeraile that her brother had been excommunicated and St. Leger, in a fit of fury, rode to the priest's shack and demanded that he withdraw the sanction of excomunication. The priest tried to explain to his Lordship that it was only the Bishop who could do that and Lord Doneeraile in a rage beat him with his horsewhip. He also whipped his ageing housekeeper who tried to save the priest.

Later the priest had the timereity to sue Lord Doneraile, but could not get a barister to act against a Lord of the realm until John Philpott Curran, a young barister gradually making a name for himself, took the case to court in Cork. It was most unusual for a priest to sue in a Protestant court in the first place, but to sue a Lord of the Realm generated intense interest and the court in Cork was crammed to capacity to watch proceedings. They got their money's worth as Curran's oratory and legal astuteness convinced the Protestant jury that Lord Doneraile's treatment of a fragile old man and his elderly house maid was a dispicable act. The priest got thirty guineas compensation and Lord Doneraile left the court publically humiliated.

The early 19th Century

The 1st Viscount (of this new era) was succeeded by his son Hayes in 1787 who served as the 2nd Viscount until 1819. During his tenure Fishpond Lane, a public road that ran through the Park towards Castletownroche and Killavullen, was closed down and a new road built around the edge of the demesne to the east and south (two hundred years later it is still called "The New Road"). This work allowed further development within the Park. A new avenue was constructed which meandered for a mile through the Park, over a nice stone bridge allowing his important guests fine views of the Park as they aproached the Court. This avenue exited the Park under a Triumphal Arch on the Turnpike road.

In 1820 the 2nd Viscount was succeeded by his son, another Hayes St. Leger the 3rd Vicount. He extended the St. Leger estates to their largest size by purchasing the Buttevant estate of the bankrupted John Anderson. This brought him Buttevant town, Buttevant Castle and a large area around complete with a large Military Barracks.

He in turn was suceeded by his son another Hayes St. Leger the 4th Viscount. The 4th Viscount was a noted huntsman and was master of the Duhallow Hunt for many years as well as being master or the Burton Hounds in England. He imported fresh blood from England for the Duhallow pack. Having fallen out with the Duhallow Hunt, he formed his own pack and told them he would hunt his own land in future. His property stretched for 16 miles from near Kildorrery to west of Buttevant.

The last case of rabies in Ireland?

One day Hayes St. Leger came on some local people digging out foxes. They had unearthed a young cub which they were reluctant to kill and His Lordship asked if he could have it. They agreed and he reared the fox as his pet and took it everywhere as his mascot. Unfortunately the fox lead to his eventual downfall. The fox contracted rabies and bit His Lordship as well as his coachman Barrer in early January 1887. They both went to Paris to Louis Pasteur and stayed a month getting Pasteur's new vaccination treatment and came home ostensibly cured. While Barrer never looked back, Lord Doneraile fell ill with what was described as hydrophobia or rabies in August of 1887. Though tended by the best doctors in Cork who kept in touch with doctors in London and Pasteur in Paris, Lord Doneraile was dead within a week. Thus began the legend that Lord Doneraile may have been the last person in Ireland to have died from rabies.

His widow, Lady Doneraile, was Mary Anne Grace Louisa Cunningham, a niece of Robert Emmet. She had married the 4th Viscount in 1851. She left Doneraile after her husband's death and later lived in France. She was a noted gardener and horticulturist. Curtis's Botanical Magazine Dedications Vol. LXXXIV was dedicated to her memory, noting that:

> During her reign at Doneraile she made the garden amongst the most beautiful in Ireland without in any way detracting from the great natural beauty of the demesne.

The magazine also noted:

> During the time she lived in Grovenor Street her window flower-boxes drew many visitors, who might have been seen standing in admiration before them. It was for the skillful way in which they were planted and for their beauty that she was awarded the Royal Horticultural Society medal...

After her husband's tragic "death she made her home at Grésy-sur-Aix in the old Chateau de Fontanil where she had every opportunity to indulge her love of gardening..."

Lord and Lady Castletown

Having no son at the time of his death, the Viscount title went to his cousin, Richard Arthur St. Leger 5th Viscount. However, he died three years later in 1891 and the title passed to his nephew, Edward St. Leger the 6th Viscount. Edward was the organiser of the Wimbledon Lawn Tennis Championships for many years. While the title went to the 5th and 6th Viscounts, Doneraile Park was managed by the 4th Viscount's daughter

Ursula Clare Emily St. Leger and her husband, Barney Fitzpatrick 2nd Baron Castletown of Upper Ossory, commonly referred to as Lord Castletown of Upper Ossory until his death in 1937. Apparently they spent six months each year in Doneraile and six months in Granston Manor in Ossory. They were very popular with the local people. Lord Castletown was a member of the Gaelic League and gave a lot of employment with a local sawmill and in tending the estate. Canon Patrick Sheehan, author and Parish Priest of Doneraile, was an occasional dinner guest in Doneraile Court. Oliver Wendall Holmes, Chief Justice of the United States, having met Lord and Lady Castletown in London, was invited to visit them in Donereaile. It has emerged in recent years that Holmes was smitten with Lady Castletown's beauty and lively intelect and they kept up a lively exchange of love letters for a number of years. Lord Castletown as Chancellor of the Royal University of Ireland was a prominent negotiator for the establishment of the National University of Ireland in 1908.

Lady Castletown died in 1927 and Lord Castletown ten years later. The management of the estate then passed to Edward St. Leger the 6th Viscount until he died in 1941. He having no son to succeed him the title and estate went to his brother Hugh St. Leger the 7th Viscount who came back from farming in New Zealand and lived a quiet life with his wife in Doneraile until his death in 1967 when the title became extinct.

The estate was then managed by trustees who sold it to the State in 1969. It was the last remnant of the St. Leger estates that were first purchased in 1630 and brought to an end the St. Leger association with Doneraile after 340 years and eleven generations.

Gardens and landscape

From the beginning of their ownership of Doneraile Court, the St. Legers were very conscious of following all the latest gardening fashions from England. The earliest garden of note was the walled and terraced garden attached to the castle. Richard Cox, writing in 1687, noted that:

> Donerayle, a sweet seat and a pretty market town belonging to the heir of St. Leger, once Lord [President] of Munster, who kept his Presidency Court here and had a fine house and a curious park adjoining...

The fine house had been destroyed by Lord Castlehaven's army in 1645 and was reerected as a barracks for the army as Doneraile Court was being developed south of the river. The "curious park" was a walled and terraced area near the castle, which was a forerunner of more extensive landscaping as security improved. The conservation of this seventeenth century garden alone was worth the price paid for the Park in 1969.

The map of 1728 (Figure 2) shows much more development with orchards and fir groves as well as gardens around Doneraile Court. The mention of Fish Pond lane indicates it was a well established feature in 1728, though there was no access across the river. However, Smith's notes of 1750 suggests considerably more development. Later in the Georgian period, Capability Brown's ideas are put into practice with the ponding of the river and the construction of a small cataract facing the Court. Both these features are still present. The open uncluttered vistas radiating out from the Court were also developed as were the carefully planned groves of trees to gave an impression of clearings in a primaeval woodland. The building of some fine ha-ha fences enhanced the vistas from the Court, while the Victorian period saw the planting of many exotic trees as they were discovered and brought back to these islands. At the same time, flower and vegetable cultivation developed to the level of an ongoing commercial enterprise.

Lavish praise of the Doneraile ladies

Some St. Leger ladies also got high praise from visitors over the years. Arthur Young mentions a cottage in the park built by Lady Doneraile "...which was a credit to her good taste". Townsend, in 1810, noting the great ornamentation of Doneraile Park, mentions the late Lady Doneraile, describing her as a lady "of most superior understanding" who did much to embellish the the pleasure grounds. Dr. John O'Donovan, later of Ordnance Survey fame, visited in 1817 and noted the Park was "a very happy mixture of the antique English and Flemish style and the picturesque of nature". He also noted the "Forest Garden" planted by Mrs Stawell, a daughter of Lord Doneraile. All this layer-upon-layer of gardening styles and landscaping has survived intact, or almost, to the present day.

Conclusion

With no intrusion of modern development, Doneraile Park is now a very special place. Its legacy to modern Ireland is it's uniqueness, its stunning landscape and fascinating history. It encapsulates an era that has passed without compromising it's relevance to modern Ireland. The 340-year association of the St. Leger family with both Park and town is one of the longest family associations in post medieval Ireland. As such, it is a prized part of our heritage. It is a living relic of a bygone age which must be seen in the context of its time. Doneraile Court and its environs thus deserve a special place in our national conservation endeavours and should be protected for generations to come.

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Doneraile Park

Recollections and reflections

Fergal Mulloy

Introduction

Following almost three and a half centuries, the St. Leger connection with Doneraile had drawn to a close. However, a lingering spirit in the form of a distant St. Leger connection had taken up residence in Doneraile Court in the late 1960s with expectations of reigniting the St Leger dynasty. This coincided with the dawn of a national awakening to the value of our natural heritage. The meeting of these two elements began with an unscheduled curiosity visit and ended in the transition of Doneraile demesne into a national treasure.

The curiosity visit

On a Saturday morning in the spring of 1969 I visited Doneraile Court (Figure 1) near Mallow Co. Cork with Fred Courtier, Chief Wildlife Forester in the Forestry Commission. At that time I was a Wildlife Officer (there was only one!) in the then Forestry Division of the Department of Lands.

Fred and I were on an official three-week tour of Ireland, north and south, giving talks to forest staff in both jurisdictions, about the importance of wildlife within forests, their role in society and their importance to biodiversity. We were also emphasising the importance of controlling grey squirrel and the more recently introduced mink. We visited as many deer parks as possible and recorded their populations. Much of this information was published in 1970 by the British Deer Society in its journal *Deer*. We travelled in a Forestry Commission Land Rover driven by Fred Courtier, and carried a 16 mm film projector, films and a collection of mink and squirrel traps as well as other paraphernalia.

I was aware of the Doneraile herd of red deer, which was reportedly introduced in 1895. I also knew from an official in the Land Commission (Mr. Jim McAllister) of the ownership claim by a Mr. St. Leger (i.e. right of inheritance). A Vietnam veteran from the United States, Mr. St. Leger's claim was, at that time, before the House of Lords. We were also aware from Jim McAllister that there were moves afoot by the Land Commission to purchase the estate, but this was being held up by the St Leger claim.

Mr. St. Leger answered our knock on the door of Doneraile Court. We explained our mission and were invited inside. He elaborated about his claim to ownership and the plans he had for the demesne. We were given permission to view the demesne and come back with our opinion.

We walked the 166 ha. demesne and formed the opinion that this was indeed a very special place, which in the event of a breakdown of St. Leger's claim, would make an excellent public park. Few Irish estates, if any, possessed the character of this beguiling and intact, walled demesne. The combination of its landscape configuration, natural beauty, red deer herd and architectural heritage made both the demesne and Court unique within the Republic of Ireland. It pressed all the right buttons that would fulfill the requirements of a publically owned park where Irish wildlife would be an important component. Portumna Forest, which eventually became a Forest Park, had similar attributes but lacked the rich undulating sylvan landscape of Doneraile.

We returned to Doneraile Court and again met Mr. St. Leger. We expressed our views on the magnificence of the demesne and the need of such a place to have greater public access. Although he didn't agree with us, we parted on good terms. Unfortunately, I never met Mr. St. Leger again.

Meeting Departmental officials

When we returned to Dublin we reported on our tour to a HQ group chaired by Henry Gray, Assistant Secretary (Forestry Division) (Figure 2). Others in the group included Martin Feehan, Inspector General (a fancy title for Chief Inspector, but without the Assistant Secretary status) and Tim McEvoy, who subsequently became Chief Inspector. During the meeting Fred made a passionate case for seeking public ownership of the demesne. He outlined in strong and convincing language the enormous benefit to society of its being made a forest wildlife park. Fred's advocacy was strong and very persuasive citing the need to build on the special qualities and high educational value of the demesne. His soft Devonshire accent and his undoubted charm made a huge

Figure 1: *Doneraile Court c. 2001 (photograph: Seamus Crowley).*

impression. At that time Henry Gray was Vice Chairman of the Council of Europe's *European Conservation Year 1970* Committee. This committee sat in Strasbourg and was chaired, I understand, by Prince Bernhard of the Netherlands.

Henry Gray's aspirations

As the Land Commission and the Forestry Division were within the same Department (Department of Lands) it is assumed that Henry Gray would already have been aware of the possibility of the Land Commission purchase. However, following Fred Courtier's presentation, his focus was drawn to it and he set about paying a visit to Doneraile himself. He told me later that he liked what he saw and was fully behind the concept of making it into a Forest Park with wildlife being an important element. He was clearly determined to use his powers of persuasion to secure its transfer to the Forestry Division should it be purchased. He had a strong and forceful personality with a "difficult to work for" reputation. He led the Forestry Division more by dictate than consensus and his will usually prevailed. His position on the Strasbourg Committee gave added impetus to his Doneraile mission. At that time there were only a handful of parks in state ownership (Phoenix Park, St. Stephen's Green, Botanic Gardens, the Bourne Vincent Park and perhaps one or two others). A dedicated Forest Wildlife Park would have had a particularly sweet ring about it in the run up to *European Conservation Year 1970*. I believe he saw it as a means of pursing a wider agenda of building a more important nature conservation role for the Forestry Division.

Henry Gray frequently spoke of how, in many European countries, nature conservation was the remit of the Forest Service. At that time the Land Commission had recently been given responsibility for developing "Game" tourism. This was

Figure 2: *Henry Gray, while he was Principal Officer in the Forestry Division in April 1961. Photograph taken at Shelton Abbey by the author while he was the Assistant Superintendent in the Forestry College.*

to fulfill an expectation in the Government's *Second Programme for Economic Expansion* published in 1963 to earn revenue from the provision of game shooting for tourists. Two officers within the land Commission (Michael Skehan and Eamon Grennan) were trained in Game Management and a Scientific Advisor (Fergus O'Gorman) recruited from University College Cork. State support was being provided to Regional Game Councils to build up the resources. It was becoming increasingly obvious that Henry Gray would seek to have this responsibility transferred from the Land Commission to the Forestry Division after European Conservation Year. Indeed this eventually happened in the spring of 1971 when responsibilities for wildlife and game development were transferred to the newly named Forest and Wildlife Service.

A vision of an all-embracing Department of the Environment

When European Conservation year was at its height, Henry Gray had instructed his Departmental officials to draw up plans for a broad ranging parliamentary bill to encompass all the environment issues. The mandarins within the Department of Local Government (subsequently to become the Department of the Environment) must have been aware of this take-over bid and effectively torpedoed its passage at an early stage. The Taoiseach, Jack Lynch T.D., opened the National Conference of European Conservation Year, which took place in November 1970. He used the occasion to define the role of the Department of Lands by drawing up a parliamentary bill which would be confined to Wildlife Conservation and would replace the Wild Birds Protection Act 1930 and the Game Birds Preservation Act 1930. The momentum and ambition that drove Henry Gray to generate a super Department of the Environment were thus clearly thwarted. The Wildlife Bill was eventually published in 1973 and passed into law in 1976. It was not enacted, however, until 1977, seven years after European Conservation Year.

Purchase of Doneraile estate by the Land Commission

The summer of 1969 saw a campaign to influence the trustees of Doneraile to proceed with the sale to the Land Commission. The claim for ownership by Mr. St Leger was beginning to flounder. A meeting was arranged by Henry Gray for me to meet the Chairman of the trustees (a solicitor from Clontarf as far as I recall), who quizzed me on the rationale and the benefits of making Doneraile Demesne into a Forest and Wildlife Park. Public appreciation of nature conservation was extremely low in the late 1960s. At that time for instance, no legal protection existed for wild fauna and flora or their habitats. Whatever protection existed related only to birds (i.e. the two 1930 acts). Equally, there were no nature reserves, no nature trails and ecology was a topic mentioned only in textbooks.

In the meantime Henry Gray used his undoubted influence as Assistant Secretary to persuade the Departmental Secretary (Tim O'Brien) and Minister (Sean Flanagan T.D.)

to smooth the legal and political obstacles to its takeover. It also helped that the trustees were anxious to offload the estate in the event of a likely collapse of the House of Lords judgment against St. Leger. There was also good rural support in the hinterland for a Land Commission takeover. Many thought that the Land Commission would divide the area among deserving farmers and there was a strong lobby to influence the Minister to that effect. Equally however, there appears to have been strong support within Doneraile itself to have access to the demesne, particularly since such access had evolved over the years with the demise of the St. Leger family influence.

The Land Commission purchase took place in November 1969. The purchase included the area within the demesne walls, Doneraile Court (Figures 1 and 3) and lands outside the walls of the demesne including some woodlands and part of the current Kilcolman Bog nature reserve. The purchase price is reported to have been £56,000. However, all such purchases were paid in "Land Bonds" that invariably had a lower cash value.

Traditional Land Commission Policy – Doneraile an exception to the rule

The policy of the Land Commission was always focused on acquiring suitable estates for division among local farmers or farmers from congested districts, thereby increasing their holdings to a viable status. Non-agricultural land resulting from such sub-divisions were usually handed over to the Forestry Division, which was prohibited from acquiring agricultural land. At that time, and indeed up to the mid-1980s, a designated Land Commission inspector was based in every Forestry Divisional office to ensure that no agricultural land was purchased for forestry purposes.

Figure 3: *Doneraile Court and demesne c. 1993 (Photograph: Seamus Crowley).*

It is against this background that the concept of allocating Doneraile Demesne to the Forestry Division would have been alien to normal policy and is testament to the dominating position Henry Gray had acquired within the Department. Political representations were indeed made shortly after its acquisition for the land to be divided. There was also a strong political representation for housing to take place on part of the demesne.

The Minister for Lands at that time was Sean Flanagan TD. He was a charismatic and well-known national personality with a strong sporting reputation, having captained All-Ireland winning Mayo teams in 1950 and 1951. He too was a frequent visitor to Strasbourg and was a keen advocate of European Conservation Year 1970. He was the official chairman of its Irish Committee, with Henry Gray as his vice Chairman. Sean Flanagan told me during a trip abroad in 1972, that he had supported Henry Gray's vision for Doneraile, although it would have had adverse political repercussions had adverse declined a request for division. He was made an honorary member of Doneraile Golf Club in or about 1970, perhaps in recognition of the good work …or possibly for more ulterior/Machiavellian motives. In spite of strong representations to sub-divide the demesne for housing and golf, the political and administrative will prevailed and no division or allocation took place.

Transfer to the Forestry Division

The transfer of Doneraile Park to the Forestry Division allowed onsite work to commence. In the early years, resources unfortunately did not in any way match the urgent need to perform basic repairs, let alone any development work. For instance, it took many years of subterfuge to repair the perimeter wall, with funds being spirited out of the "Fence Repairs" subhead. Moreover, the "Doneraile Park" was viewed by some senior managers as a dilettante's exercise and, worse still, that money spent in the Park was at the expense of normal forest operations elsewhere.

However, as the years passed and particularly as the official opening of the park approached in 1984, resources gradually became available and approximately IR£50,000 was spent annually on development. Meanwhile, the Georgian Society, motivated principally by Desmond Guinness, obtained a lease of the house and environs and set about a modest restoration of Doneraile Court.

Coillte commenced operation on 1st January 1989. In preparation for this event all wildlife functions, including the enforcement of the Wildlife Act 1976, were transferred to the Office of Public Works. The administration of Doneraile Park was part of this transfer. Seamus Cowley, who had provided skilled and sensitive guidance of park management for almost a decade before the transfer, continued to oversee its ongoing improvement up to his retirement.

Conclusion

The task of generating awareness of nature conservation in Ireland effectively began with *European Conservation Year 1970*. The transfer of Doneraile Park to the Forestry Division under the administration of Henry Gray played an important part of that process. That Henry was an ambitious man is certainly true, but it was that ambition which also kindled a curiosity about nature that, even today is serving the nation well. The chance visit to Doneraile on that spring day and Fred Courtier's strong advocacy apparently sparked an idea in Henry Gray's mind that he seized upon to complement his involvement in European Conservation Year.

It is clear that Doneraile was therefore, part of a wider agenda as perceived by Henry Gray. The absorption of the wildlife remit into the Forestry Division was reasonably straightforward for Henry Gray, but the game element became a particularly contentious issue. Being used to having a compliant workforce, the Game movement was particularly suspicious of his motives and mutual distrust ensued. This distrust was so strong that one particular Game Council made complaints to the Taoiseach in early November 1971. This resulted in a boycott threat by that Regional Game Council of the upcoming National Conference of Regional Game Councils unless Henry Gray stepped down. As sometimes happens in life, Fate intervened with the sudden and unexpected death of Henry Gray. His successor, Billy Duggan, was a consummate diplomat who moved quickly to diffuse the situation.

The joint legacy of Henry Gray and Sean Flanagan was the saving of Doneraile from threatened division. To this must also be added the growing public appreciation of Nature Conservation and the lead into the Wildlife Act of 1976. Habitat Protection, Nature Reserves and Special Conservation Areas were alien concepts in the Ireland of the late 1960s. Doneraile played an important part in this journey and deserves a special place in the process that awakened the national consciousness to the benefits of nature protection to society. For their contribution we must all be grateful.

Postscript

The Land Commission was abolished under the Land Commission (Dissolution) Act 1992, 111 years after it was established. Sean Flanagan T.D. initiated the case for its abolition while still its Minister, a unique political act as ministers do not normally advocate the abolition of their own departments! It was certainly a reflection of his strongly independent personality.

Henry Gray's ambition for a new all-embracing Department of the Environment under his control collapsed in November 1970. Ironically a new Department of the Environment emerged in time and is currently responsible for all wildlife matters, albeit divorced from forestry, while the Office of Public Works is now responsible for Doneraile Park. Henry Gray's vision came to pass in the way he may not have wished, nonetheless a resource of great value emerged. *Plus ça change, plus c'est la même chose*.

Acknowledgements
I would like to thank Seamus Crowley and Fergus O'Gorman who, by their close proximity to the events outlined, alerted me to specific elements, jogged my memory on others and willingly made themselves available for comment and suggestions. My thanks also to Professor Padraic Joyce for his suggestions and comments and who, although unconnected with the occasion, was conscious of the environment within which it occurred.

Trees Woods and Literature – 39

A Walk in the Woods

Not long after I moved with my family to a small town in New Hampshire I happened upon a path that vanished into a wood at the edge of town. A sign announced that this was no ordinary footpath but the celebrated Appalachian Trail [AT]. Running more than 2,100 miles along America's eastern seaboard, through the serene and beckoning Appalachian mountains, the AT is the granddaddy of long hikes. The Virginia portion alone is twice the length of the Pennine Way. From Georgia to Maine, it wanders across fourteen States, through plump, comely hills whose very names- Blue Ridge, Smokies, Cumberlands, Catskills, Green Mountains, White Mountains - seem an invitation to amble. Who could say the words 'Great Smoky Mountains' or 'Shenandoah Valley' and not feel the urge, as the great naturalist, John Muir, once put it, 'to throw a loaf of bread and a pound of tea in an old sack and jump over the back fence'.

For the Smokies are indeed a very Eden. We were entering what the botanists like to call 'the finest mesophytic forest in the world'. The Smokies harbour an astonishing range of plant life - over 1,500 types of wild flower, 1,000 varieties of shrub, 530 mosses and lichen, 2,000 types of fungi. They are home to 130 native species of tree. The whole of Europe has just 25... (When at last the ice sheets drew back, the native northern trees began the long process of returning to their former territories. Some like the white cedar and rhododendron are only now reaching home, a reminder that, geologically speaking the ice sheets have only just gone).

And yet, here is the thing. Shenandoah National Park is lovely. It is possibly the most wonderful national park I have ever been in, and, considering the impossible and conflicting demands put on it, it is extremely well run. Almost at once it became my most favourite part of the Appalachian Trail... Surprisingly considering its modest

> dimensions and how little room there is for real back country, the park is remarkably rich in wildlife; bobcats, bears, red and grey foxes, beaver, skunks, raccoons, flying squirrels and our friends the salamanders exist in admirable numbers, though you don't see much of them as most are nocturnal or wary of people. Shenandoah is said to have the highest density of black bears anywhere in the world - slightly over one per square mile.
>
> In 1840, during the presidential campaign, Daniel Webster gave an address to 20,000 people on Stratton Mountain in Vermont. Had he tried the same thing twenty years later (which admittedly would have been a good trick, as he had died in the meantime) he would have been lucky to get an audience of fifty. Today Stratton Mountain is pretty much all forest, though if you look carefully you will still see old cellar holes and the straggly remnants of apple orchards clinging glumly to life in the shady under-story beneath the younger and more assertive birches, maples and hickories. Everywhere throughout New England you find old tumbledown field walls, often in the deepest, most settled woods- a reminder of just how swiftly Mother Nature reclaims land in America.

These extracts[1] from the beginning, middle and towards the end of Bill Bryson's account of his adventures with his friend, the reformed alcoholic and pseudonymous Stephen Katz, along the Appalachian Trail do not do full justice to the colourful pilgrimage. The book, *A Walk in the Woods*, describes the fraught preparations involving often unlikely and inappropriate equipment and provisions, the dawning realisation that this would be no walkover, nocturnal encounters with real or imagined forest denizens, meetings along the way with eccentric fellow travellers such as Chicken John who was perpetually getting lost, near heatstroke and hypothermia and the acceptance, when faced with the formidable "one hundred-mile Wilderness" in Maine, that the trail had beaten them, are described by Bryson with gentle (and sometimes not so gentle) irony. He also makes some well-honed observations on a few American (US) environmental, industrial and societal institutions and their impacts.

The explorers did, however, manage a considerable achievement, walking 870 miles in four main stages or a third of the AT from spring to autumn. The first stage from Georgia to Tennessee, skipping next to Virginia and New Hampshire where Katz took a break leaving Bryson to explore the trail in New Hampshire and Pennsylvania

[1] Reproduced with kind permission of the author.

by motor incursions, extended by daily walks. Finally the pair came together again to complete the Wilderness in New England. In total, 99.7 miles of boreal forest without facilities or paved roads, dotted with lakes and steep valleys and mountains lay before them. A short distance into the wilderness saw Katz lost and Bryson spending the next day searching for him. Katz realising he had missed the trail and rambling on in a random fashion fortunately found it next day where Bryson, retracing his steps, found him. The final paragraphs describe what then ensued.

> There was something in his look. 'You want to go home?' I asked. He thought for a moment, 'Yeah I do'. 'Me too'.
>
> I won't say that the experience changed our lives and I can't speak for Katz but I certainly gained an appreciation and respect for woods and wilderness and the colossal scale of America. I lost a lot of weight and for a time was remarkably fit. Best of all, these days when I see a mountain, I look at it slowly and appraisingly, with a narrow, knowing gaze, and eyes of chipped granite.

Bryson went on to further writing and travelling and he and Katz, who remained sober, kept in contact, but didn't hike together again. *A Walk in the Woods* isn't necessarily just about the trail and at times the observations about the woodlands seem sparse, but the landscape of the Appalachians as shaped by its geology, the people he met there, its historical context and the nature of the institutions which manage and impinge upon it, give a valuable and intriguing insight into a substantial slice of American life.

William McGuire (Bill) Bryson was born in Des Moines, Iowa in 1951. Despite dropping out of college in the 1970s to travel, he has had a remarkable academic and literary career. He met his wife, Cynthia Billen, in England, returning with her to De Moines to complete his degree. He went back to England in 1977 and lived there with his family in North Yorkshire working, among other fields, as business copy editor of the Times and deputy news editor of the Independent. He returned once more to America in the 1990s where he settled in New Hampshire and wrote this book. He now lives, again, in England since 2003 and has been involved in public issues there, particularly the protection of the English countryside, and is the recipient of many honours including chancellorship of Durham University, an honorary doctorate from Kings College, London, an OBE, Fellow of the Royal Society and the James Joyce literary award, nearer to home, from the UCD L&H Society. He is the author of numerous humorous travel books, anthologies on place, language, science and history as well as memoirs and biographies. A Walk in the Woods was first published by Doubleday in 1997, which edition includes attractive line drawings of the AT by David Cook. The book is now the subject of a film starring Robert Redford and Nick Nolte and was released in the current year (one wonders about the casting decision to use veteran actors to portray their forty something-year-old counterparts). A selection of his other books include *Lost Continent* (1989), Notes from a small Island (1996), *A Short History of Everything* (2003), *Life and Times of a Thunderbolt Kid* (2006), *One Summer, America* 1927 (2013) and most recently *The Road to Little Dribbling (2015)*.

Gerhardt Gallagher

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 Long Journey in a Short Time by Tony Gallinagh. Published by Gallinagh Publishing. August 2015.

Arboretum: A History of Trees Grown in Britain and Ireland by Owen Johnston. Published by Whittet Books. 2015.

***A Song for the Forest** by Tom Mongan. Published by the author. 2014.

Climate Cultures: Anthropological Perspectives on Climate Change by J. Barnes and M.R. Dove. Published by Yale University Press. August 2015.

Diseases of Temperate Horticultural Plants by R.A.T. George and R.T.V. Fox. Published by CABI. November 2014.

***Europe's Changing Forests: From Wildwood to Managed Landscapes** by Keith J. Kirby and Charles Watkins (Editors) Published by CABI. June 2015.

Forests: A Very Short Introduction by Jaboury Ghazoul. Published by Oxford University Press. May 2015.

***God's Trees - Trees, Forests and Wood in the Bible** by Julian Evans. Published by DayOne Publications. 2013.

Hawthorn: The Tree that has Nourished, Healed and Inspired through the Ages by Bill Vaughan. Published by Yale University Press. June 2015.

Hidden Natural Histories: Trees by Noel Kingsbury. Published by University of Chicago Press. 2015.

***Kilmacurragh: Sourced in the Wild – The Moulding of a Heritage Arboretum** by Megan O'Beirne. Published by Systems Publishing. March 2015.

Landscape Photographer of the Year: Collection 8 by Charlie Waite. Published by AA Publishing. November 2014.

Longleaf, As Far as the Eye Can See: A New Vision of North America's Richest Forest by Bill Finch, Beth Maynor Young, Rhett Johnson and John C. Hall. Published by University of North Carolina Press. October 2012.

Norwegian Wood: Chopping, Stacking and Drying Wood the Scandinavian Way by Lars Mytting (translated by Robert Ferguson). Published by MacLehose Press. October 2015.

Our Once and Future Planet: Restoring the World in the Climate Change Century by Paddy Woodworth. Published by University Of Chicago Press. 2013.

Ponderosa by Carl E. Fielder and Stephen F. Arno. Published by Mountain Press Publishing Company. April 2015.

Ponderosa: Big Pine of the Southwest by Sylvester Allred. Published by University of Arizona Press. March 2015.

Shades of Green: An Environmental and Cultural History of Sitka spruce by Ruth Tittensor. Published by Windgather Press. 2015.

Sustainable Forest Management: A Global Overview by Aduardo Hapke. Published by Callisto Reference. 2015.

***The Company of Trees: A Year in a Lifetime's Quest** by Thomas Pakenham. Published by W and N. September 2015.

The Gymnosperms Handbook: A Practical Guide to Extant Families and Genera of the World by James W. Byng. Published by Plant Gateway Ltd. 2015.

The Irish Garden by Jane Powers. Published by Frances Lincoln. April 2015

The Man Who Made Things Out of Trees by Robert Penn. Published by Particular Books. October 2015.

The Native Woodlands of Scotland: Ecology, Conservation and Management by Scott Wilson. Published by Edinburgh University Press.

The Rainforests of Britain and Ireland: A traveller's guide by Clifton Bain. Published by Sandstone Press. November 2015.

***The Wisdom of Trees: A Miscellany** by Max Adams. Published by Head of Zeus. October 2014.

The Woodland Homeland by Brett McLeod. Published by Storey Books. July 2015.

Treasured Trees by Masumi Yamanaka and Christina Harrison. Published by Kew Publishing. March 2015.

***Tree and Forest Measurement.** (3rd ed.) by P.W. West. Published by Springer. March 2015.

***Tree Morphogenesis; Book 1: Reduction via Thinning** by David Lloyd–Jones. Published by the author and available for Kindle. 2013.

Trees in Towns and Cities: A History of British Urban Arboriculture by Mark Johnston. Published by Windgather Press. 2015.

Trees: A Handbook of Forest Botany for the Woodlands and the Laboratory by H. Marshall Ward. Volumes 1 to 5 published by Forgotten Books as a Classic Reprint from the original in early 1900s. June 2015.

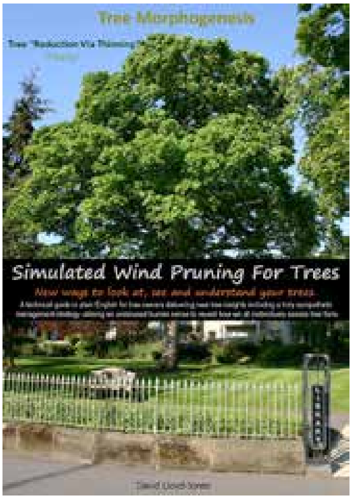
We are the Champions: Champion Trees of South Africa by Enrico and Erna Liebenberg. Published by HPH Publishing. 2015.

Wood Characteristics: Description, Causes, Prevention, Impact on Use and Technological Adaptation by Christopher Richter. Published by Springer. 2015.

World Tree Story: History and Legends of the World's Ancient Trees by Julian Hight (Ed. Anna Carr). Published by the author. 2015.

Tree Morphogenesis; Book 1: Tree Reduction via Thinning

David Lloyd-Jones, 2012
Tree Morphogenesis Project, Knutsford, United Kingdom
available from www.TreeMorphogenesis.com
146 pages. Softbound. ISBN 9780993011405
£30 (including P&P)



This interesting book sets out to challenge the reader to understand how they see and consequently deal with trees. It is written by a practicing "career arborist" and in a narrative tone throughout. The text is a playful mixture of business sense and strategy with many delightful observances on arboriculture, personnel management and tree admiration. As the cover proclaims, this first book in the series seeks to guide owners, arborists and even viewers alike in new ways to look at, see and understand trees. The book describes a method to simulate wind-pruning of trees –or rather to imitate the type of crown reductions that wind action carries out naturally. Interestingly, though clearly written from the perspective of a professional arborist to influence other arborists and tree surgeons, the author deliberately makes the point that tree owners and clients need such knowledge themselves to ensure that any professional work carried out on their trees is done as sympathetically as possible.

The central idea of the book is to consider the natural processes that give us the shapes of trees around us. He describes the biological background to the basic growth that gives a tree its characteristic shape and discusses the various parameters that affect and change the growth phases of a tree as it matures. He holds late spring frosts and mid-summer droughts as the main causes of successive growth phase changes to trees in temperate climates. In other words, a tree's growth oscillates between "periods of apical dominance characterised by straight expansive and vigorous growth separated by periodic growth phase changes that allow branches to fork, twist and turn in an amorphous form." Following this is a discussion of the way a tree's structure is affected by its growing environment. As an example, a sycamore seedling is followed in a series of illustrated steps to maturity, its winter outline carefully and realistically sketched, leading to the discovery several pages later that the example was based on reality and a photograph shows the tree's bare silhouette against a clear sky. The point being, that a mature tree's morphology has been shaped by "the culmination of events affecting it throughout its life". The changed forms which result from such growth phase changes are often viewed as being weaknesses e.g. the acute forks or bent branches which can fail in high winds. However, the author describes how such apparent weaknesses act in the individual tree's favour by allowing a partial failure (instead of a catastrophic one e.g. the whole tree blowing down or snapping) during a storm.

There is a section about natural resonance in trees and how to measure it. Resonance, or its opposite dissonance, being the process that dissipates wind energy in a tree. There is a nice description of the author being high up in a tree during a strong wind and noticing the change of the resonance frequency as he tried to climb down. He discusses how resonances can be additive among various parts of a tree, to build to dangerous levels of swaying during high winds. Therefore, by subtly changing the structure an arborist can detune a tree and make it less likely to fail in a storm.

At this point the theory of "reduction via thinning" (RVT) is finally fully described as a methodology to simulate the types of pruning that wind would otherwise make to trees, though in doing so an arborist would make smaller cuts rather than rips which heal faster. Thus, the process of reducing a crown might be "more sympathetic than nature itself" as it involves the removal of a small number of carefully chosen primary foliage bearing branches back to natural pruning points. The aim being to subtly reduce wind resistance, confer structural strength to trunk and root systems while retaining the shape, functionality and character of the tree. There are a series of illustrated comparisons between RVT and some harshly treated and lopped specimens which make a compelling argument. The author ends a section advocating that where trees are concerned, "we should trust them more and prune them less".

What I really found interesting was a discussion of the idea of accessing a latent ability of humans to judge or assess tree symmetry – essentially to trick ourselves into bypassing conscious thought to reach and experience a primitive and instinctive reaction to a natural form. This ability was used by the author to help train groundsmen (and tree owners) to provide useful and succinct information to climbers in the course of a pruning job, to inform about the effects of branch removal on overall tree (crown) symmetry. Apparently, with only a small amount of practice, useful information and directions could be shouted up to the professional. with the saw saving time spent descending and ascending again, or in the amount of training given to ground teams.

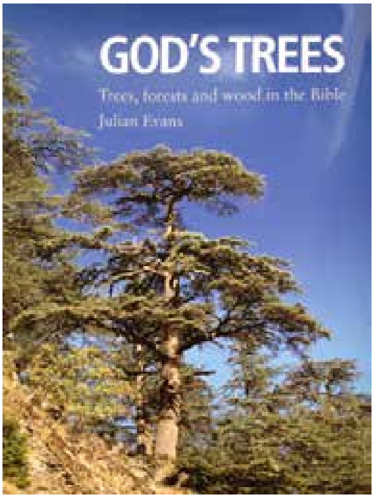
There were a couple of things this reviewer didn't appreciate about the book. It was a little frustrating to read through the background and theory of RVT, to be introduced to the practicality of how to go about it, only to be told to wait until the next book to be shown the full practical end of RVT, i.e. identifying and choosing points of cuts etc. The book has also been rather poorly produced and would have benefited from a professional editing. That said, the personal touch of the well-intentioned and extremely experienced author (as an arborist) is much closer as a result. The presentation of some of the photographs was poor and could easily been improved. The case studies included at the end of the book, however, were excellent to have. The author describes five real-life examples of applying RVT with a series of before and after photographs, and discusses the merits and difficulties of applying RVT in quite different situations and to a range of tree species.

Despite the irritations mentioned I am very much looking forward to the next book in the series, as apart from the professional expertise being discussed, David Lloyd-Jones comes across as a very down to earth, personable and entertaining author.

Brian Tobin

GOD'S TREES - Trees, Forests and Wood in the Bible

Julian Evans.
DayOne Publications, 2013.
Hardback. 208 pages. ISBN: 978-1-84625-410-9.
£20



This is the first authoritative publication to focus on *Trees, Forests and Wood in the Bible*. It includes stories of how they were used and sometimes abused, by early man. Written by Professor Julian Evans, former professor at Imperial College, London who is well known to Irish foresters from his many visits here to lecture on broadleaf species. He is the current President of the Institute of Chartered Foresters (ICF) and Chair of the Forestry Commission's Expert Committee on Forest Science. He is an elder within the leadership team of his church in Alton.

There are many references to trees in the Bible and the story which is most familiar to us is probably the story of Adam and Eve and the forbidden fruit, the apple (*Malus domestica* (Borkh.)). However, the apple is not native to biblical lands and it seems that domestication of the species was much later than figs and olives. Therefore, Professor Evans assures us that Eve did not take an apple. We are not certain which fruit she was tempted by … so after all those years of belief, this element of the story is firmly debunked! The tree that is mentioned most frequently in the Bible is the cedar of Lebanon and in this book we learn why King Solomon imported so much cedar for his temple. Like oak in these islands, the cedar was the largest and most common tree in the land of the Old and New Testament. We also learn that juniper was used in the floor of the temple.

Regarding Noah's Ark, we know little about the type of wood that was used in its construction. We can only speculate, but it appears that it was most likely the Mediterranean cypress (*Cupressus sempervirens* L.). We are given the approximate dimensions of the Ark which held the record as the largest ship ever built until the early 19th Century. Its construction was no doubt a monumental undertaking as it would have required hundreds of men and oxen to fell and haul the logs to the construction site and indeed as many more to shape and fit the planks and beams to ensure that the vessel was watertight.

The olive tree is mentioned in almost half of the books of the Bible and olive oil facilitated the smooth functioning of religious and social life in biblical times. It had a myriad of widely varying uses including lighting, cooking, flavouring, cleaning, healing and cosmetics. Incense, derived from the frankincense tree (*Boswellia sacra* Flueck.), was an important element of religious ceremonies. It is not native to Israel or Egypt but comes from the Horn of Africa. Its introduction in c. 1465 BC is the first recorded tree introduction. Another gift to the infant Jesus was myrrh. Even more precious than frankincense, myrrh comes from a large woody shrub of the semi-desert. There are frequent references to pine trees in the Bible. There are several pines which are native to the Mediterranean area but only one, Aleppo pine or Jerusalem pine (*Pinus halepensis* Miller) which is native to Israel. It has been widely used in afforestation and looks similar to our native Scots pine (*Pinus sylvestris* L.).

Also mentioned frequently is palm. In Ireland, the palm sprays used in Palm Sunday religious ceremonies are generally sourced from whichever conifer is most readily available in the area, but in the bible a reference to palm meant the date palm (*Phoenix dactylifera* (L.)) or Doum palm (*Hyphaene thebaica* (L.) Mart.).

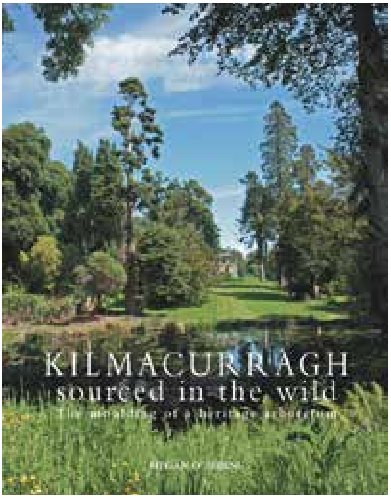
In the New Testament there are references to Christ's crucifixion beginning with the Garden of Gethsemane. It is not, however, clear what type of wood was used in the cross or the type of tree used for the crown of thorns, although the latter is believed to be the Christ-thorn (*Ziziphus spina-Christi* (L.) Desf.). A tree which is not unlike our holly, it sprouts a copious supply of large thorns at its base to prevent grazing by animals but there are smaller and fewer thorns higher up the stem.

At the end of this book, there is a very useful compendium outlining the trees named in the Bible and trees that the traveller can see when visiting the eastern Mediterranean region.

John Mc Loughlin
Business Editor of the Society of Irish Foresters
Chairman of the Tree Register of Ireland

Kilmacurragh: Sourced in the Wild The Moulding of a Heritage Arboretum.

Megan O'Beirne
Systems Publishing, 2015.
Hardback 183 pages. ISBN: 978-1-905404-21-6.
€30.00



Ireland is blessed to have such a wonderful gem as the National Botanic Gardens at Glasnevin in Dublin. It is often mentioned in the same sentence with Kew and Edinburgh. The relatively recent acquisition of Kilmacurragh Arboretum as a sister property is seen as a wonderful addition to the Glasnevin Gardens. Kilmacurragh is located in Co. Wicklow aka "The Garden of Ireland".

Any arboretum or garden of the standing of Kilmacurragh deserves to be celebrated by being the subject of a quality book.

In her book, the author, Megan O'Beirne, is brave enough to attempt such an ambitious task. She is brave in that she is not a professional horticulturist or botanist. On the cover of the book she is described as a writer and visual artist who became enchanted with Kilmacurragh.

The author is also brave in that she sets out not only to describe and photograph the arboretum and its plants but to chart the history of the property and its former owners, the Acton family, in the context of Irish history – a daunting task.

The book succeeds on a number of levels:

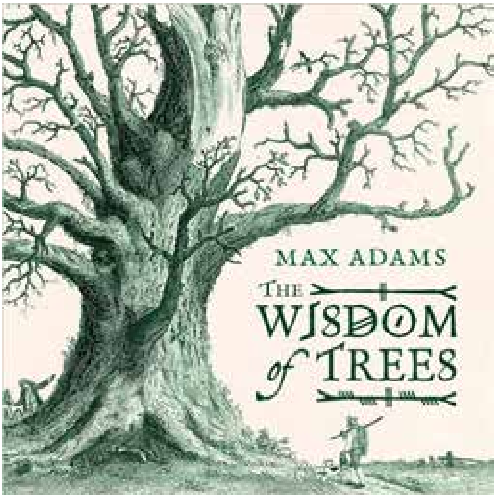
- it is beautifully illustrated with photographs taken by O'Beirne herself;
- it provides a large body of information, horticultural and historical;
- it is well designed and laid out.

However, even by the author's own admission as evidenced by a list of errata on her website, it contains several inaccuracies. This is unfortunate and could have been avoided either by having a suitable professional as a co-author or by more judicious editing. Nevertheless, the book is a suitably impressive addition to any coffee table and is an entertaining and engrossing read for anyone interested in trees and gardens.

Kevin J. Hutchinson

The WISDOM of TREES

Max Adams.
Head of Zeus. 2014.
Hardback. 256 pages. ISBN: 978-1-78185-546-1.
£14.99



The Wisdom of Trees is a fine example of a new genre of book, written by non-foresters for the wider public, which looks at trees from an alternative perspective. The over-riding value of such publications is that they give us foresters a helpful insight into the public's attitude to trees and forests. As trees are the largest living organisms on the planet, people tend to have strongly held views on their presence in the landscape. In recent years, this awareness has been heightened by the media. Furthermore, associated issues such as climate change and tropical deforestation have helped to focus increased attention on trees. The author of this book, Max Adams, is an archaeologist and a teacher of "tree history" and he also manages an area of woodland in County Durham. The author says he named the book *The Wisdom of Trees* not because trees are wise per se, but because we would be wise to learn from them.

It is his contention that trees have an economic value primarily and if we wish to restore the benefits of an active, wooded landscape then our trees and woodlands must provide sustainable economic and social benefits for the inhabitants of this landscape. Many publications in this genre eulogise about the beauty of trees and their undoubted biodiversity value, but fail to adequately recognise their fundamentally important economic values. Adams bemoans the fact that since wood was largely replaced by metals in the 19th century, it is no longer seen as a strategic resource. In Britain, he says that the overwhelming majority of the broadleaf resource is in private hands and very little of it is managed with a "production" objective. It is timely to ask if we in Ireland will follow a similar path.

The author also questions why there is so little coherent thought given to the issue of what we might do with the trees being planted today, when they mature. Foresters know that over the course of history, trees have been used for many different purposes; indeed this reviewer can recall life without Medium Density Fibreboard (MDF), Oriented Strand Board (OSB), glulam beams and other engineered wood products.

Wearing his archaeologist's hat, the author postulates on how humans developed over time by learning from the forest. He argues that man learned how to fell trees by observing the beaver at work. We may also have invented the axe and the saw as a result of these observations since both these valuable tools are based on the use of a "tooth". The beaver also makes dams - useful for diverting streams, catching fish and generally manipulating water flow. The birds showed us how to use twigs as the essence of nest building is the "knitting" of flexible materials to produce a rigid structure. It may sound far fetched but the basket, the hurdle, the mat, the coracle and even our primitive "clay and wattle" hut may have been inspired by the nests of birds. Resins show us the potential for glues, bark and climbers for rope, fruits for nutrition and medicine. Then there is rubber and the paper made by wasps to construct their nests. It is difficult to disagree with his hypothesis. Just think of the many uses to which a child can put a simple stick …and adults too!

Max Adams argues that trees are very patient but he neglects to emphasise that foresters must also be patient; that we need to take a much longer term view of woodland management. Adams relates the story of the elderly French Marshal who asked his gardener to plant a tree for him. The gardener protested that the tree was slow growing and would not reach maturity for a hundred years. The Marshal interjected "In that case, there is no time to loose; plant it this afternoon!"

Overall this book is a pleasant and interesting read which contains some rare nuggets of information between its covers. Especially noteworthy is his theory that governments tend to worry about trees only in wartime or when trees are dying in great numbers. In other words, governments worry about trees only when it is already too late! Is he correct? I'm afraid he may be ….. but, for all our sakes, I hope he's not!!

John Mc Loughlin

A Song for the Forest

Tom Mongan.
Lettertec Ireland Ltd. 2014.
Paperback. 213p. ISBN: 978-1-910097-16-8.
Available from the author:
Creggauns, Letterfrack, Co. Galway.
€10.00 (or €13.00 incl. p&p)

In writing *A Song for the Forest*, Tom Mongan has produced a delightful book which recounts his travels and experiences while working as a "forestry plough operator" around Ireland during the 1960s. His odyssey leads us through a "hidden Ireland", to places which are well off the beaten path and tourist trail. However, Tom also brings us to towns and even to some cities since his story coincides with the "show-band era". Long, dreary days on the plough were relieved by the bright lights and music at night, when great dreams and youthful ambitions were granted full rein.

Tom began his career as a forest worker near his home in Letterfrack, Co. Galway. Back then he was happy working in the forest and living the days for the night as dancing was uppermost in his mind. However, on his way home from work one evening he fell off his new racing bike and was rushed to hospital in Galway with severe head injuries. When he recovered, several months later, he returned to the forest only to find that his job was gone. Undaunted, Tom wrote to Head Office as follows: "A Chara, I wish to apply for a position as a plough operator with the Forestry Department". Not knowing the correct address, Tom decorated his envelope with nothing more than "Forestry HQ, Dublin" – evidently, there was no need for Eircode back then! One way or another, his letter did the trick and in due course he received the following, equally curt response "Report to Derrybrien Forest next Monday week at 8.00 am to commence three months training as a machine operator". Following his training he was sent to the Nephin area of Co. Mayo and was based in Crossmolina. From there he moved to Castlepollard, Co. Westmeath where he purchased his first car - a VW Beetle. In those days the Beetle was the foresters' car of choice as it was very reliable, cheap to run and, most importantly for travelling on forest roads, it was well sprung. Next, Tom moved to nearby Lough Sheelin and then back to his own county of Galway, although he was still 80 miles from home in Letterfrack. Following this to Co. Meath again, to Carnaross near Kells. He then moved to Mountbellew, where he remembers the forester in charge (the late Jim Cronin) was a real gentleman.

Tom rarely records people's full names and perhaps this is just as well, as the following little story will illustrate. One day, when ploughing near Finea in Co. Cavan, a neighbouring farmer called him for help to rescue a cow from a deep drain. Unfortunately, the well-intentioned rescue mission coincided with a surprise inspection by a forestry chief from Dublin. In Tom's own words this man considered himself to be not just "one of the gods" but the Supreme Being!! His name is not divulged but those of us who are of a certain vintage will enjoy the mental exercise of lining-up the suspects. Tom concludes the episode with this on-the-button comment: "This high ranking official did not understand country ways. If you want to get co-operation from the locals you have to be flexible. Back then, just as now, forestry depended on the goodwill of the local people. After all who else can you turn to for help in an emergency?"

Unfortunately, the outcome of Tom's misadventure was that he was "put back on the spade" as punishment. Having thus served his time, he later returned to the ploughs. This time he went many miles from home to Waterville, Co Kerry and later to Mullaghareirk, Dunmanway and Ballyvourney, Co. Cork. He clearly enjoyed his time in Cork and Kerry and writes glowingly about the magnificent scenery and the friendly people he met there. Tom finally returned to where it all began in south east Galway. He met his wife in nearby north Clare and decided (or was persuaded) to give up his travels shortly afterwards.

Without the forestry plough, which was developed after World War II, whole tracts of peatland and uplands could not have been forested. Afforestation became possible because tracked machines, a legacy of the war, could travel these sites which were incapable of supporting wheeled tractors. The public forest estate would certainly be very meagre today without the extensive areas of peatland planted from the 1950s until the 1980s. Ploughing continued until the late 1980s when it was superseded by mounding which is a silviculturally superior system of ground cultivation. However, ploughing was a very cheap cultivation method and planting on the ribbons, particularly with a dibble, was very fast as up to a 1,000 trees a-day could easily be planted. It should be remembered that all this took place in an era long before environmental impacts were considered; in the days when the *Ploughing Plan* comprised no more than getting the job completed at the least possible cost and this usually entailed making the ribbons as long as possible and getting water off-site as fast as possible.

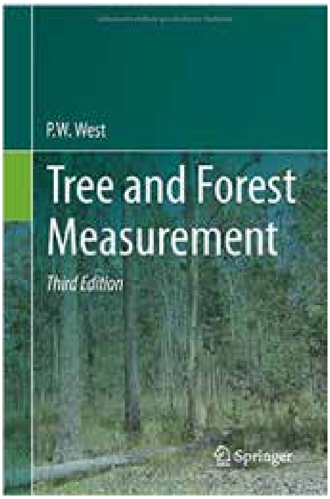
Nowadays, an entire generation of foresters is unfamiliar with the forestry plough in much the same way as younger farmers are unfamiliar with corn-threshing. The only difference is that vintage machinery shows, which are now quite common, give farmers an understanding of the threshing process. However, the forestry plough is no more. There were three distinct types of ploughs. The Cuthbertson Double Mole Board plough which threw up two ribbons was the most common form of ploughing. However, it proved disastrous silviculturally as the tree roots tended to follow the ribbon and when storms came the entire ribbon with the trees often blew over. The Single Mole Board plough was mainly used to put in drains across the double mole board ploughed area and often necessitated two crawler machines pull it. Finally, there was the Clarke plough which was used on dry but rocky ground usually to break up the iron-pan. These ploughs had an ingenious device called the "shear-pin" which was the weakest link in the chain so when the plough head hit an immoveable object the shear-pin broke, thus saving the plough from serious damage. The famous James A. Cuthbertson & Sons company of South Lanarkshire in Scotland, which spearheaded the development of these ploughs, is still thriving. However, nowadays it is better known for the manufacture of snow ploughs!

Books such as this, together with *A Social History of Forestry in Ireland* and Tom Briody's *The Road to Avondale* and *In the Service of the State*, Tony Gallinagh's *A long Journey in a Short Time* and Cecil Kilpatrick's *Northern Ireland Forest Service – A History*, have made a hugely important contribution to recording the story of Ireland's afforestation programme. Other national programmes such as rural electrification have been well documented for posterity. Huge credit is due to Tom for persevering with this project. In doing so, he has set a fine example for others to follow. The value of this book is that it contributes to a preservation of our country's store of forestry history and stories - before "time steals our past forever". Tom has blazed the trail, he has ploughed the furrow. The Society of Irish Foresters should now follow his lead.

John Mc Loughlin.

Tree and Forest Measurement

P.W. West
Springer International Publishing, 3rd edition, 2015.
Softback. 214 pages, ISBN 978-3-319-14707-9.
€74.89



Tree and Forest Measurement is a technical text with wide appeal. This revised edition includes the latest developments in the measuring of biomass and remote sensing. The author, with many years of experience as a forestry lecturer, covers the standard mensuration topics such as the age-old task of evaluating how much wood or biomass is in a forest. In a logical framework, three scales of measurement are examined: the individual tree, the forest stand and large forest areas. The book begins with a useful discussion on the essential ideas of accuracy, bias and precision when taking measurements.

The author moves on to arguably the most useful measurement taken in a forest, that of the stem diameter or DBH which is known to correlate with several variables. Height measurement is discussed next, and as for DBH, the concepts and theory behind the different methods and the instruments used are described, with an additional discussion on the challenges involved in direct measurement. Adopting this formula throughout, volume comes next, which begins with direct measurement and moves on to the widely used formulae which estimate sectional stem volumes using diameter and length of the section (the formulae of Huber, Smalian and Newton) and finishes with centroid sampling. A further chapter is devoted to equations that estimate the stem volume from the DBH and height of the stem and to taper equations which can be used to produce volume estimates and to evaluate the potential product assortments obtainable from the stem.

In the biomass chapter, the reasons for measuring the biomass of a tree and each of its components are provided (estimating the amount of carbon sequestered, research into photosynthesis, bioenergy production). Direct measurements of biomass and the challenges involved are followed by the more practical estimation methods such as the use of allometric equations and expansion factors.

The stand level chapter includes a fine exposition of the exceptionally useful point sampling system for measuring basal area, as devised by Bitterlich. The straightforward calculations of stocking and quadratic mean diameter are followed by a discussion of site productivity and dominant height and finally the important concepts of current annual increment and mean annual increment are described. The topic of yield class and related concepts are not covered, presumably since the author is based in New Zealand, where these concepts are not in common practice.

The last few chapters of the book are devoted to sampling which is required to estimate the area of a forest or conduct an inventory. The concepts of population, sample, mean, variance and uncertainty link the previously mentioned tree and stand measurements to the large forest area chapters. A selection of different sampling methods are discussed including the factors determining when they can be used and the level of accuracy associated with each method (simple random sampling, sampling proportional to size, sampling proportional to prediction, stratified sampling and model-based sampling).

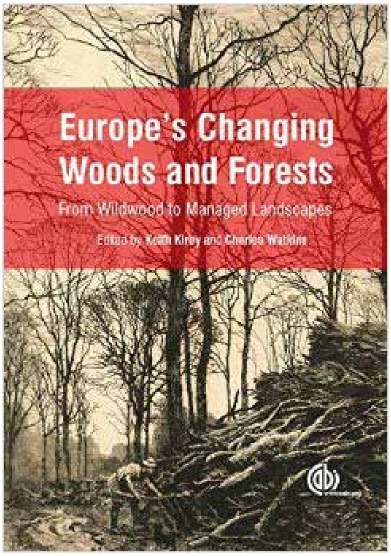
The penultimate chapter outlines how to map and calculate forest area using a survey. An account is given of the principles behind the global positioning system (GPS) which is becoming relevant to more than just foresters as more mainstream devices (e.g. phones and apps) are utilising GPS. Remote sensing tools used from the air and also satellites are next described as are tools such as LIDAR and spectral photography. Regrettably though, there is only scant reference to drones; aside from their use outside the world of forestry (delivery of consumer purchases and surveillance), these low cost devices have great potential for surveying forest areas.

The book has a multitude of equations and functions in use worldwide and is loaded with references while, at the same time, the text is very readable. Abstracts have been added to each chapter in this edition making the topics more accessible to students or to those interested in particular topics. The appendices are complete with metric-imperial conversions, a glossary of technical terms (which have also been highlighted throughout in bold), the Greek alphabet (used to label parameters in the equations throughout) and basic trigonometry. With all of the above in mind, the book seems to be aimed at students and designed as a supporting textbook to a mensuration course however, it would certainly be useful to anybody working with forests and this reviewer recommends it as such.

Andrew McCullagh

Europe's Changing Woods and Forests From Wildwood to Managed Landscapes

Edited by Keith J. Kirby and Charles Watkins.
CABI Publishing 2015.
363 pages. Hardback. ISBN: 978-1-78064-337-3
€125



Those of us living in Ireland often bemoan the fact that only small fragments of natural (or mostly semi-natural) woodlands remain for study and enjoyment. The situation in the U.K. is broadly similar. Conversations often refer to the relative abundance of such woodlands or forests in Continental Europe. But is this the case? We often confuse areas that have apparently always been under forest cover but influenced by man to varying degrees with true natural woodlands.

This book, as the title suggests, deals with this and many other issues about the history of Europe's woodlands.

This is a large and detailed book in the tradition of many other CABI forestry publications. Its 363 pages are divided into 5 parts with 24 chapters having content from 36 authors. As a result it is very wide ranging content with many different writing styles evident. Because of this diversity of content it is appropriate to list the 5 parts so that potential readers/purchasers may be more fully informed.

The 5 parts are:-

Part I: Introduction and overview.

Part II: The variety of management across European woods and forests.

Part III: How plants and animals have responded to the changing woodland and forest cover.

Part IV: A variety of woodland histories.

Part V: Lessons from the past for the future.

Part I. discusses the current composition of European woods and forests and puts them in a global context. It traces the evolution of modern forest landscapes starting with looking at them before the influence of farming practices. There is a useful section on methods used in studying forest and woodland history.

This is followed in Part II. by chapters dealing with the diversity of woodland management systems throughout Europe. Of particular interest to Irish readers is the chapter by Peter Savill which looks at High Forest Management and the rise of even-aged stands. Having worked in Northern Ireland for a period, Peter is familiar with Irish plantation forestry and makes reference to it in this chapter. The chapter on "Close to Nature Forestry" is interesting given the increasing emphasis on that system in recent years.

Part III. is quite specialised in content in that it deals with the response of plants and animals to changes in woodland and forest cover. Though of more relevance to those specialising in ecology and wildlife management, nevertheless, it makes interesting reading for practicing forest managers.

In Part IV. we are treated to a mixed menu of woodland histories including Italy, Poland, Britain, Ireland, France and Sweden. This section illustrates very well how there are many and diverse woodland histories in Europe and how difficult it is to encompass them in one volume. Each chapter in its own way contributes to our understanding of the subject.

The final section of this book, Part V., attempts to teach us lessons for the future based on our past actions and experiences.

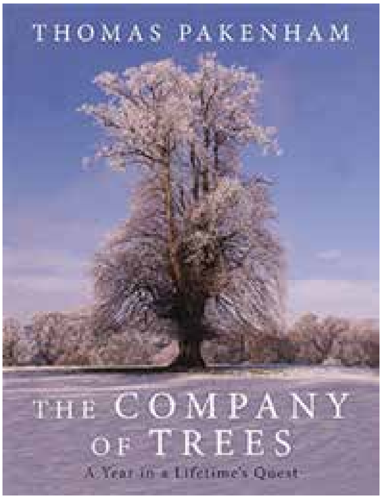
This book is a most welcome and useful addition to the forestry and woodland library. It will appeal not only to foresters but to environmentalists, geographers and historians.

One criticism, though relatively minor, is the concentration of the colour illustrations in an eight-page section in the middle of the book which reduces their relevance to the text.

Kevin J. Hutchinson.

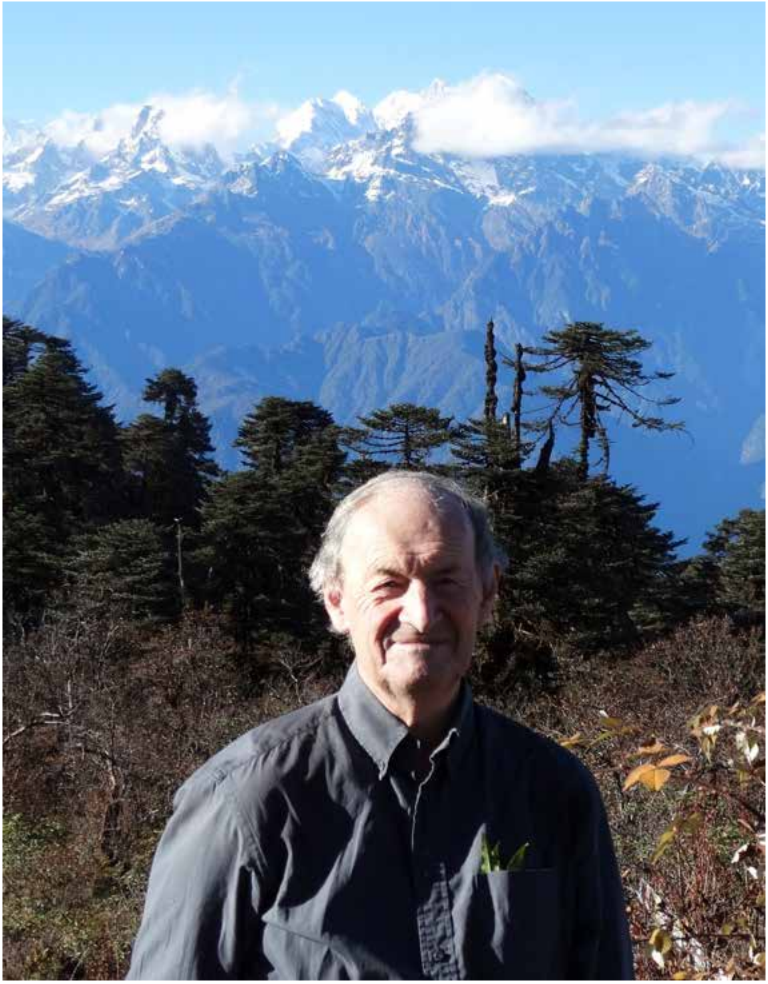
The Company of Trees: A Year in a Lifetime's Quest

Thomas Pakenham
Weidenfeld and Nicolson 2015
Hardback. 216 pages ISBN: 978-0297866244
£30



Thomas Pakenham's record on writing best-sellers about trees is well established and further enhanced by his latest venture *The Company of Trees, A Year in a Lifetime's Quest*. A fascinating arboreal love story, told by a man with a passion for trees, plants and exploration, it is a pleasure to read.

Written in the form of a memoire, the book recounts the author's quest to establish an arboretum at Tullynally, just west of Castlepollard, Co. Westmeath, his numerous hazardous seed and plant searching expeditions and his efforts to preserve old trees and historic woodlands. Structured in the form of a travel diary and focusing in particular on 2013, he reflects on travels to far off places in Argentina, China, India and Tibet in search of interesting specimens. Following the footsteps of the renowned plant hunter, Joseph Hooker, he goes in search of the great *Magnolia campbellii var alba* in the Himalayas, climbing mountains, including the Nyima La Pass in India, and scrambles through dense forests in all kinds of weather. This forms the agenda for someone so inclined and is all aptly and amusingly described. The author also recounts visits to eastern Patagonia, giving impressions of the remaining Southern beech (*Nothofagus* spp.) forests and the last of the of the giant Monkey Puzzle trees, "a species the Victorians loved and the Edwardians hated". Accounts of these journeys, and the winners and losers in terms of plant survival at Tullynally, add substance to the story with practical lessons for those planting trees. Arising from his time in the Chilean Andes, the jewel in the crown at Tullynally is now a young attractive specimen of *Fitzroya cupressoides* (Alerce) grown from a cutting, the parent of which is more than two thousand years old. An expedition to Tibet's amazing Tsangpo Gorge, leads to a fruitful exploration of the Rongchu Valley, yielding more than 100 bags of seeds, including the Tibetan golden oak, the Tsangpo cypress and blue-stemmed maples. Seeds from south west China are used to create a Chinese garden following the irregular Sharawadgi design fashionable there in the seventeenth century.



Thomas Pakenham in Sikkim state in India, with a Himalayan backdrop to enchant any classical plant hunter. The Orion Publishing Group kindly granted permission to use selected pictures from The Company of Trees.

The ginkgo tree (*Ginkgo biloba* L.) is the author's favourite and there is particular focus on its evolution and history. Referred to in China as a "Duck's foot", or more romantically as the "Grandfather-grandchild tree", its impressive growth rate at Tullynally, as well as that of the Dawn redwood, *Metasequoia glyptostroboides* (Hu and W.C. Cheng), are attributed to our warming climate.

Pakenham has great respect for sycamore, "the king of European maples" and is critical of "the ethnic cleansing campaigns" of the "Taliban purists" who seek to denude Ireland's landscape of "alien" plants and trees, including sycamore and beech. In suggesting sycamore may have been introduced in or around the year 1500 or perhaps as far back as one thousand years ago, he disagrees with the policy that species can only be deemed native if they reached the island before the most recent ice age.

The decline of the great demesnes, such as Carton, is lamented. While acknowledging that society and fashions change, their demise and conversion to building sites and golf courses represent an opportunity to learn from the past. Tullynally is to be commended for addressing the challenge of managing the change needed to ensure sustainability. From a forestry viewpoint, this includes an interest in commercial coniferous plantations and a realisation that they form an integral part of the package, affecting the bottom line in a positive manner, thereby enabling essential work to be carried out. The impact of storm damage, climate change, the arrival of pests and diseases, and an almost devastating fire in July 2013 (in which the author almost perished), have all presented considerable challenges and threats to keeping Tullynally. It is heartening to read about how such difficulties are being addressed and surmounted, including even the maintenance of the ancient walls.

Two chapters on determining the age of yew trees and the famous oak woodlands near Shillelagh in Co. Wicklow make interesting reading. Despite visits to a multitude of ancient yews in Britain and Ireland, determining their age remains a problem to be resolved. At Shillelagh, the conservation of the oak woodland at Coolattin caused a political storm in the late 1980's. Thanks to the efforts of the Irish Tree Society and others, part of the woodland at Tomnafinnoge was purchased by Wicklow County Council and set aside for conservation. Uncertainty continues over its age, provenance and timber quality. Nonetheless, a walk through and along the banks of the Derry River, is an excellent way to ponder and wonder.

The book has a good bibliography and index and of course, some colourful and hauntingly beautiful pictures.

Michael Carey

Michael Carey is a Forestry and Management Consultant and the author of *If Trees Could Talk - Wicklow's Trees and Woodlands over Four Centuries*.

An 18th century beech in the parkland at Tullynally.

Society of Irish Foresters Study Tour to Slovakia

30th September – 4th October 2014

On Tuesday 30th September, 40 members of the Society departed Dublin Airport en route to Slovakia, via Kraków in southern Poland. At Kraków Airport we were met by Professor Ladislav Paule, Faculty of Forestry at the University of Zvolen, Slovakia, who would be our genial host and ever-patient guide and interpreter for the duration of our visit. After a brief stop for lunch, we set out for the famous Wieliczka Salt Mines, a UNESCO cultural and heritage site. Here, we marvelled at the grandeur and scale of the mine which has almost 250 km of galleries. We also learned of the strong interdependence between mining and forestry in Slovakia, the mines being enormous users of timber.

Slovakia is a very mountainous country. Its highest point is 2,655 m above sea level. Only 11% of the country is classified as agricultural land, whereas it has a forest area of 2.17 million ha or 41% of the country. However, the forest cover is unevenly distributed. Most of western Slovakia is an extension of the Great Hungarian Plain and is treeless whereas the mountainous areas, where our tour was based, can boast almost 70% forest cover. There is a long and proud tradition of forestry in Slovakia. The forestry industry here has been regulated since the early 15th century when King Sigismund decreed in 1426 that harvesting areas must be specified and prohibited the practice of "wander cutting". Beech (*Fagus sylvatica* L.) (28%), spruce (*Picea abies* (L.) H.Karst.) (24%) and pedunculate oak (*Quercus robur* L.) (10%) are the principal tree species. The country's total growing stock is 472 million m^3 (2013). The annual increment is 11.95 million m^3 and the annual harvest is 8.23 million m^3. Approximately half the annual harvest is composed of hardwoods, but the proportion is decreasing. There are also five very large national parks which cover approximately 4% of the country.

Slovakia (48,845 km^2) is less than half the size of the island of Ireland and has a population of 5.4 million inhabitants. The Tatra Mountains extend across the north and centre and there are only small areas of lowland in the south west and east of the country. Our tour was based in the town of Poprad, the gateway to the High Tatra Mountains on the first night and in Banská Bystrica in the Low Tatra Mountains for the following two nights. On our final night we were based in Vienna, close to the city's airport, in readiness for our return flight to Dublin.

Pat O'Sullivan, Tour Convenor

Wednesday, 1st October

Our tour began with a visit to the museum at the Tatra Mountains National Park, where we were shown a film on the history of the national park. It was established in 1949 and, at that time, undertook both standard forest operations and nature conservation. However 20 years ago those two functions were separated and henceforth the State Forestry Enterprise (LESY Slovenskej Republiky or LESY SR) looked after forest operations while the National Parks Service had responsibility for nature conservation.

Dr Susana Homosova then gave a very informative lecture on forestry in the High Tatra Mountains with particular reference to the challenges and problems that arose following the major wind-blow of 2004. A similar catastrophic storm had occurred 89 years previously. Normally, the climate in the High Tatra Mountains is relatively warm and dry, with low rainfall but it can become quite windy. Soils in the area are generally poor, shallow and rocky. The bedrock is granite so therefore acidic, however there are occasional calcareous hills.

In February 2004, almost 12,000 ha of forest were blown and flattened in less than 20 minutes during a storm which recorded wind-speeds of up to 200 km/hr. Many of the blown trees remained alive for almost three years afterwards so the European bark beetle (*Ips typographus*) survived and multiplied in the blown material. Subsequently they moved out and began attacking healthy, standing trees nearby, thus causing much additional damage. From 2005 to 2013 almost 7,000 ha of forest were devastated by the beetles. They have now spread into several areas of the natural forests where forest operations have never taken place. This contradicts the claim made by many environmental groups that natural forests would not have problems with insect attack as they are in a healthy equilibrium state because there is no human intervention. In 2013, the extent of bark beetle damage in the forest was assessed using aerial photography and it is currently equivalent to the extent of the original windblown in 2004. It is believed that the warming effect associated with climate change has exacerbated bark beetle problems, a number of years ago it only occurred up to an altitude of 1,200 m but now it is found at elevations of 1,400 m which is the upper tree line. The warmer temperatures have led to increased leader growth and this increases the trees susceptibility to wind damage. The number of years taken to remove the blown material, together with the reduced practice of debarking logs and recently enacted environmental legislation which prohibits debarking of blown material in protected areas, have all combined to make bark beetle damage a very serious problem for the foresters. Even today, 10 years after the storm, almost 73,000 m^3 remains to be harvested.

After our visit to the museum, we separated into two groups, with most of the group ascending the mountains with Professor Paule and others remaining below to visit the local botanic gardens. On the field trip we travelled high into the Tatra

Mountains using cable cars and ski lifts. Unfortunately, visibility was poor due to fog but Professor Paule's commentary and explanations were most interesting and entertaining. We walked through an area which had previously carried a fine crop of Norway spruce but was now being replanted with pine (*Pinus sylvestris* L.) and larch (*Larix decidua* Mill.). He also pointed out an area of mature Norway spruce which had suffered significant bark beetle damage. He stated that the problem of acid rain has declined significantly over the past 20 years as many of those polluting factories had either closed or now had effective pollution control systems installed. We saw circular heaps of brash and he explained that there is a requirement to leave between 10% and 30% brash on site for biodiversity purposes. He said that in Slovakia natural gas had begun to displace firewood for domestic heating in recent years, but now that natural gas was getting more expensive, there is a significant resurgence in firewood sales in the forest.

In the afternoon we travelled to the town of Liptovský Hrádok to visit a seed processing plant which is owned by OZ Semenoles, a state enterprise. This plant has been in production since 1923. Here we met the Managing Director, Martin Honec and the Operations Manager, Jan Sochor. OZ Semenoles buys only certified cones for processing and then sells the seed to forest nurseries throughout Slovakia. In 2014, this plant processed 127 tonnes of cones, although it has a maximum capacity of 250 tonnes. The cones are collected from approved seed-stands only and the resulting planting stock must be planted back in the same seed zone that it was collected in. In the seed processing plant a water flotation system is used to separate seed from waste material

Figure 1: *Listening intently to Professor Paule are Ted Farrell, Kieran Moloney, Gerhardt Gallagher, George Hipwell, Owen O'Neill, Stacey Bradley and Pat O'Sullivan.*

(necessary for larch and spruce) and most dead/unviable seeds sink to the bottom of the container. Each seed-lot has its own unique number, zone of origin and a record of the elevation at which it was collected. Nowadays they process seed from many species including broadleaves. Acorns are immersed in water at 42 ˚C for 2.5 hours to kill any fungi or moulds which may be growing on them. Finally, the seeds are treated with fungicide and can then be stored at -3 ˚C for up to three years. Beech seeds are also treated with fungicide and can be stored for up to five years at -7 ˚C. This facility has the capacity to store up to 50,000 kg of seed in its cold store. In the off-season they operate a profitable business processing rose hips to produce rose hip tea.

Overnight - Banská Bystrica   Eugene Griffin

Thursday, 2nd October

Banská Bystrica, on the Hron River, was our base for the next two days. The city's name derives from Banská, meaning a mine in Slovac and Brystrica, meaning a fast-flowing river. In Slovakia, forestry and mining are very closely linked. In the early 19th century the ever increasing demand for mine support timbers led to an over-exploitation of forests and this threatened both the forestry and mining industries. In 1807, the Austro-Hungarian Emperor, Franz Joseph established the country's first college of forestry. It was attached to the Mining Academy in Banská Bystrica, it was later renamed the Academy of Mining and Forestry. In an interesting aside, Professor Paule explained how it was originally planned to locate the forestry college in Prague. However, Empress Maria Theresa, fearing the bohemian charms of Prague would distract the young foresters from their studies, overruled her Minister and opted instead for the more sedate environs of Banská Bystrica. As the mother of 16 children herself, she probably understood all too well the many dangers and pitfalls of exuberant youth. A case of mother knows best!!

Our first stop of the day was at the European yew (*Taxus baccatta* L.) reserve, which is located above the village of Harmanec. This is a Natura 2000 site, as the European yew is an IUCN red listed species. Yew occurs naturally in mixed forests of beech and silver fir (*Abies alba* Mill.), usually on chalk but also on other substrates. At this stop we saw examples of yew growing naturally in mixture with beech and silver fir. This nature reserve was established in 1949 following an inventory undertaken in 1948 by the great Slovakian forester Jozef Dekret Matjovie and Professor Slovad from Prague. In the 1949 inventory they had recorded 180,000 yew trees at this site but the current population has dwindled to fewer than 40,000 trees.

The exploitation of these woods was driven mainly by demands from the mining, metallurgy and glass making industries in the area. The timber was harvested for fencing, pit props and fuelwood. Yew foliage is also harvested to make wreaths to decorate graves on All Souls feast day (1st November). Red deer (*Cervus elaphus)* browsing is an important factor limiting regeneration of the yew. Since the reserve was established and a deer management plan introduced, the reduction in tree numbers has stabilised. However further management intervention and research is necessary for this unique yew reserve to thrive.

Later we travelled further up the mountain to Rakytovce (altitude of 890 m). In the last century, the timber here had to be harvested manually and extracted using a "gravity propelled" system whereby the logs were slid down the slopes on precarious-looking timber chutes before they were loaded onto boats for transport to the sawmill. The forest roads we travelled along were built in the 1970s to facilitate the extraction of timber from these steep, difficult slopes. Initially, old six-wheel drive army trucks were used to haul the timber to the main road. Slovakia's most famous forester, Josez Dekret Matejovie, was a pioneer of forest regeneration systems and devised a variety of establishment methods. At one stage he experimented with a catapult system, which could sling 'balled seedlings' up to the more inaccessible slopes in an attempt to re-establish forests on these steep sites. He also advocated planting immediately after harvesting rather than waiting for several years, as was the practice then. The forests at Rakytovce were approximately 30 years old now and were regenerated naturally. Across the valley large rectangular plots of approx 5-6 ha were visible. These areas had been re-planted after felling as they failed to regenerate naturally. Slovakian forest law requires that regeneration with an average stocking level of 2,000 stems ha^{-1} must be achieved within seven years of clearfelling. This law dates from the time of Empress Maria Theresa in 1769. It is interesting to note that a felling licence is not required but detailed forest

Figure 2: *The Lord's Valley at Rakytovce*

management plans, drawn up by registered, professional foresters must be approved for each forest area. The earliest record of forest regulatory practices dates back almost 600 years to 1462 when "wander cutting" was banned by King Sigismund. This meant the forester had to prepare very specific details of location, area and the direction for harvesting operations.

After a traditional Slovakian lunch in the village of Staré Hory, we travelled further up to the picturesque former mining village of Špania dolina to learn of its copper and silver mining traditions which date back to prehistoric times. Archaeologists have uncovered mining tools close to this village which date from 2000-1700 BC. Copper from this region was identified in artifacts discovered in the Balkans and as far afield as Lebanon and Syria. In their day these richly endowed valleys have attracted some unusual visitors. For example, the alchemist Paracelsus established a laboratory here during the Middle Ages as he needed to be close to a ready supply of base metal for conversion to gold once he had "cracked the formula". Due to the intensity of mining and sheep grazing in this region, the tree cover began to decline during the 16th century. In 1565, Emperor Maximilian II introduced new forest laws which limited the level of sheep grazing; this marked the beginning of forest management in the area. This valley is also famous as a lace making centre. The ancient tradition of bobbin lace led to a craft school being established in 1883. In the centre of the village there is a unique covered stairway of 160 steps which leads steeply up to a fortified church built in 1294 which incorporates Gothic and Renaissance architectural styles. The church bell called the "Knocker", dates from the late 16th century and served to call the miners to work each morning. The last of the mines in the valley closed in 1888. Nowadays, large numbers of tourists come here to walk the many trails in the valley, for cross country skiing in winter and for mountain biking in summer.

Our next stop was the forest district office in the crater of an extinct volcano at Polana. On arrival we were greeted by a raging thunderstorm and downpour of truly biblical proportions. Our hosts from LESY SR, the Slovakian State Forestry Enterprise welcomed us with strong coffee, tea and local refreshments. Then we were treated to a hugely informative presentation on forest management in Slovakia by Dr. Peter Kováčik with support from Anna Sliacka and Vlastimil Rezek. The area of PEFC certified forests managed by LESY SR is currently 916,253 ha. In addition, two regions in Presov and Trencin District, comprising 86,556 ha, are certified under both the FSC and PEFC. After these presentations a lively and enthusiastic Q&A session ensued which demonstrated how much we have in common with Slovakian foresters. This session was aptly summarised by our Chairman for the day, as "a splendid evening of robust discussion and information exchange".

Forestry in Slovakia – Some basic facts	
Forest cover:	41%
Total growing stock:	472.0 million m^3
Total annual volume increment:	11.95 million m^3
Annual cut:	8.0 million m^3
Average volume increment	6.1 m^3
Annual profit:	**€10 million (2013)**

Brief history of forest regulation in Slovakia

1426 King Sigismund introduced the earliest harvesting regulations.

1550 A "central chamber" of foresters was established to manage the Royal Forests.

1565 Emperor Maximilian II formulated the first forest policy comprising 30 Articles.

1769 Empress Maria Theresa introduced a forest code: *Sylvarum conservadarum et lignicidii ordo*.

1754 A comprehensive inventory of forests was initiated.

Forest laws

1879 The first Forestry Act in Austro-Hungarian Empire. It remained valid until 1960.

1958 Forest Management Decree No. 75 - unified forest management plans introduced.

1960 Act No 166/1960 – The basis of all future Acts (based on shelterwood system).

1977 Act No 61/1977 – Legal protection of critical forest lands.

1977 Act No 100/1977 – LESY Slovenskej Republiky, the state forestry enterprise set up.

2005 Act No 326/2005 – Encouraged environmentally friendly silvicultural systems

Jozef Dekret Matjovie (1774-1841) is regarded as the father of modern forestry in Slovakia. He spearheaded the use of the saw to replace the axe in harvesting operations but is probably best remembered for his pioneering work on forest regeneration. A man ahead of his time in many respects, his motto was: "Preserve the forest for future generations because the forest is the precondition for preserving life on earth".

On cue, the thunder storm cleared and we headed out again up through the tiny village of Kyslinky to a beautiful alpine meadow where the huge scale of this ancient crater became apparent. It measures 11.2 km from east to west and 6.7 km from north to south; its highest point reaches 1,458 m. Formed 12 millions years ago, it is the largest extinct volcano in Slovakia. This area became accessible as recently as the late 1970s when roads were constructed. At the viewing point, Head Forester Jhan Ostrolucky described the management of his 3,800 ha forest. There are five foresters who work in Harvesting,

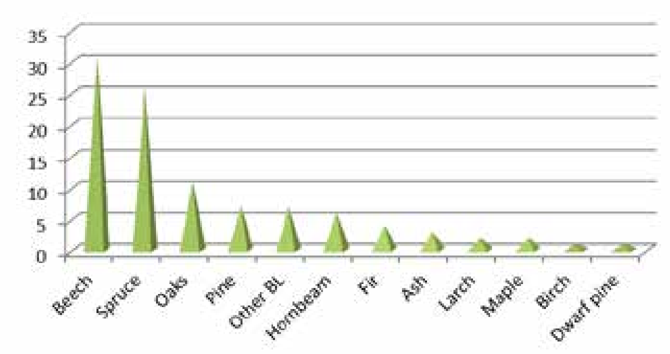


Figure 3: *Species composition of Slovakian forests.*

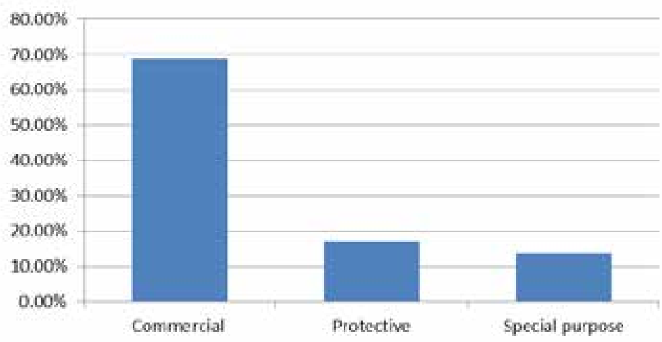


Figure 4: *Main categories of forests in Slovakia.*

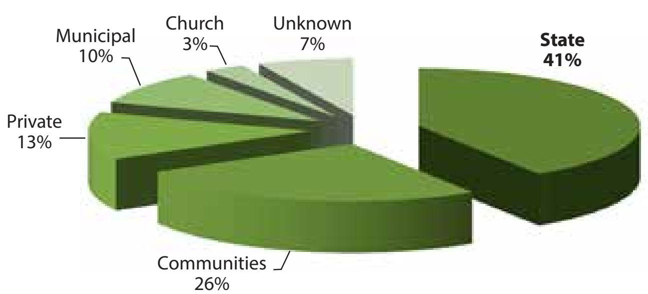


Figure 5: *Forest ownership in Slovakia (2013).*

Establishment and Planning functions and they employ contractors, who are mostly former state forest workers, to carry out all forest operations. On these steep slopes horses are used extensively for extracting thinnings and cable systems for extracting clearfelled timber. Machines are now beginning to play a greater role in harvesting with specialized processors and forwarders used where conditions are suitable.

Figure 6: *Alpine meadows at Polana in the Tatra Mountains.*

Control of poaching is the most difficult and time consuming part of the forester's job. Poachers are classified into the following three categories: food, recreation and business. Those in the latter category are the most difficult and dangerous to control. Forests in Slovakia are home to large populations of red deer (*Cervus elaphus)* which are culled as part of forest management. Red deer meat currently sells for €2.00 per kilo. The state forestry enterprise offers hunting leases to properly organised and accredited hunting clubs. There are 60,000 registered hunters in Slovakia. The brown bear (*Ursus arctos*) is also found here and is hunted under licence. The wolf is present in almost 40% of Slovakia, with the highest concentrations in the mountainous northern, central and eastern areas. It is estimated that the current population of wolves is between 300 and 400. The wolf is a protected species in Slovakia and if it kills domestic or farm animals the state must compensate the farmer. Wolves are hunted from 1st November to 15th January and the annual quota is decided by the Ministry of Agriculture. Packs of wolves can travel up to 20 km per day through their territory. Unlike the Brown bear, wolves are not known to attack humans. The forester's song in this locality is "On Polana Mountain the wolves are calling".

Overnight - Banská Bystrica Kieran Moloney

Friday, 3rd October

We departed our hotel in Banská Bystrica for the open-air forestry museum at Čierny Balog. Here we were welcomed by Dr. Michal Kofira, the museum's General Manager, together with Peter Kováčik, Vlastimil Rezek and Anna Sliacka, our friends from the LESY SR whom we had met the previous day at Kyslinky. The main aim of the museum is to educate the public about forests and their history, the work of the forester and especially, the many important societal benefits of forests. The museum was established in 2003 and it has since been extended to an area of 150 ha. It is designed to present information on forestry and forest operations in all regions of Slovakia, not just in the Ore Mountains where it is based. In Slovakia every 5,000 ha of forest has a forest officer, five foresters and two forest technicians who are responsible for all silviculture and harvesting operations within their area.

The museum trail features 80 well designed interpretation panels and, while the focus is primarily on educating children, it is nevertheless accessible and interesting to visitors of all ages. Pride of place goes to the vintage "forest railway" which runs throughout the museum. Once used for hauling timber down from the remote and poorly roaded Ore Mountains it has now become a popular attraction for tourists, as it is no longer economical to transport timber by train. Each year, in early July, the foresters organise a special "Day of Trees" at the museum when local dignitaries plant trees and there are also community sports, treasure hunts, orienteering, archery and tree climbing competitions. Most of the day's activities are directed towards children as they hold the future of Slovakia's forests.

The museum also displays an impressive collection of old forestry machines, including a working skyline system; it even has a vintage helicopter which was used for fire fighting duties during the 1970s. There is replica of a beautiful 18th century wooden church which is clad with the bark of European silver fir. The highlight of our visit was undoubtedly a superb display of old-time "horse-extraction" of timber. Here the more "senior" members of our group watched, nostalgic for times past, while the younger members stared in awe at the precise control and skill of men and horses who knew intuitively what to do …… and not a single control panel in sight!

Figure 7: *A display of horse extraction at the open-air forestry museum at Čierny Balog.s.*

The museum also features a charcoal making display. In its day, charcoal was as important as oil in today's economy. However, charcoal making was a seven day operation and the charcoal workers had to remain on site for the duration. It was difficult, dirty work and these men usually moved on to easier work when they reached their early fifties. The museum has an original 19th century forester's house. A well-constructed wooden building, it provided comfortable accommodation for the forester and his family and also served as the local forest office. Nearby were stables and barns for the forestry horses and storage of the tools and equipment. An interesting aspect of the museum was a small tree nursery which produced the main species of trees found in Slovakian forests – beech, spruce, oak, European larch and silver fir. It also featured seed beds and lined-out or transplanted seedlings – once again the practical display helping to make the work of the forester more easily understood by the many visitors. Current forestry issues, such as the damage caused by the spruce bark beetle, were displayed along the museum trails. They had examples of pheromone traps on site and information boards with details of the damage the bark beetle can do. All displays were designed to give visitors a greater appreciation and understanding of the foresters' work and the problems they encounter in managing their forests.

An interesting exhibit at the museum is a replica of the largest European silver fir in Slovakia. This tree grew in Dobroč primeval forest which was established as a reserve in 1913. When it died in 1966, the tree was 59 m tall with a diameter at breast height of 192 cm and a volume of 58 m^3. Here the tour leader, Professor Ladislav Paule explained the growth cycles of spruce, silver fir and beech in the primeval forest. On average, silver fir survives for 400 years, beech for 200 years and spruce for 300 years. A light demander, spruce is opportunistic and finds space in forest openings to ensure its survival. Studies

Figure 8: *The foresters' shrine at Čierny Balog.*

undertaken in primeval forests conclude that the minimum extent of the primeval forest is determined by the area in which these developmental phases remain constant. Thus for the mixed primeval forest the minimum area is about 40 ha, for spruce 70-80 ha, for beech 30 ha and for oak 20 ha. Our final stop was at a woodland shrine dedicated to the memory of Slovakians who lost their lives while working as foresters in different parts the world – a poignant moment which served to remind us that forestry is still a dangerous profession.

We then thanked our generous hosts and returned to Banská Bystrica for lunch before setting off on our long journey to Vienna, passing through many densely forested valleys before crossing the broad and treeless agricultural plains of south western Slovakia.

Overnight – Vienna John Mc Loughlin

Saturday, 4th October

We departed our hotel and headed for Vienna's Schwechat airport to begin the final leg of our journey home to Ireland.

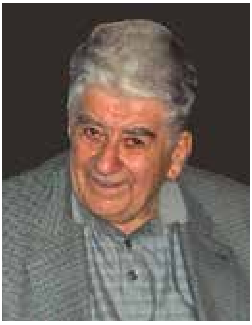
Tour Participants:

Stacey Bradley, Pacelli Breathnach, Patrick Carroll, Philip Comer, John Connelly, Robert Dagg, John Dungan, Edward Farrell, PJ. Fitzpatrick, Jerry Fleming, Gerhardt Gallagher, Tony Gallinagh, Sean Galvin, Eugene Griffin, John Guinan, Tomas Hanrahan, George Hipwell, Mark Hogan, Kevin Kenny, Tony Mannion, Pat McCloskey, Tom McDonald, Jim McHugh, Willie McKenna, John Mc Loughlin, Kieran Moloney, Liam Murphy, Frank Nugent, Benny O'Brien, Michael O'Brien, Peter O'Brien, Kieran O'Connell, John O'Connor, Liam O'Flanagan, Maureen O'Flanagan, Paddy O'Kelly, Owen O'Neill, Tim O'Regan, Pat O'Sullivan, Trevor Wilson.

Figure 9: *The forest train at Čierny Balog – one of a series of stamps celebrating Slovakia's forests which was issued in 2005.*

Obituaries

Tomás de Gruinéal
1923-2014



Tomás de Gruinéal passed away peacefully on 14th November 2014 having reached the wonderful age of 91.

He was born in Creagh, Ballinrobe in South Mayo on 28th March 1923, the eldest of seven children born to Martin and Margaret (née Caulfield). He received his primary and secondary education at CBS Ballinrobe.

Tomás studied forestry at Avondale Forestry School, Co. Wicklow from 1942 to 1945. Having grown up during the years of agricultural depression, he was convinced that forestry could be a powerful force for improving Ireland's rural economy, particularly in more disadvantaged areas. On completion of his studies at Avondale Tomás seriously contemplated returning home to support the family, as tuberculosis had claimed the lives of both his parents. However, the then Director of Forestry, Dr M.L. Anderson (who had himself lost both his parents at a young age) was sympathetic to his plight and facilitated him with a forester's post close to the family locality (see Irish Forestry, Vol. 49 No 1&2, 1992). However, tragedy affected both men quite differently. Dr. Anderson was introverted and distant with staff, whereas Tomás was always full of good spirits, was close to his staff and forever encouraged and defended them.

Major planting programmes were undertaken from the early 1950s. The Inter-Party government, influenced by Seán Mac Bride and to comply with conditions for receiving aid under the Marshall Plan, adopted a long-term economic plan which supported an annual planting programme of 10,000 hectares. Here, Tomás began the pioneering work of establishing extensive forests at Ross, Maam and Cloosh, Co. Galway. This was not an easy task, as the fiasco of an ill-advised, late nineteenth century afforestation scheme at Knockboy in west Galway was often recalled when these major afforestation schemes were proposed. However, the establishment of these major forests provided significant rural employment and, in time, became a major source of material for sawmills throughout the west of Ireland. Tomás took great pride in being able to provide sustainable jobs for men who would otherwise have been forced to emigrate to England or the USA. It is said that his only regret was that the new OSB mill was located in Co. Waterford rather than in Co. Mayo or Galway which supplied huge quantities of its raw material.

In 1957, Tomás was promoted to the inspectorate in Galway. In this role he proved to be a dedicated and innovative man who guided the establishment of afforestation on blanket bog and some elevated sites in the west of the county. In 1964, he became District Inspector in Co. Mayo. He took a keen interest in the nurseries at Foxford and Glenisland which supplied the plant requirements of the forests within the county. In 1980, he was promoted Divisional Inspector in Galway. Tomás retired in 1988, the year before Coillte was established. However, he maintained his keen interest in Society matters and in forestry in general.

In 2012, Tomás was conferred with honorary membership of the Society of Irish Foresters. In accepting this honour, he saw it not as an acknowledgement of his own efforts, but of the Herculean work of those who worked with him in very difficult conditions to establish forests in the west of Ireland. Tomás was synonymous with the west of Ireland. He was very proud of this affiliation and he always defended his staff on the basis that it was considerably more difficult to achieve comparable output from the region as it lacked the fundamental resources, particularly soil and climate, of other regions of the country.

Tomás had his own view on most matters. In the 1970s when an attempt was made to introduce uniformity in tree species names, Tomás persisted in calling lodgepole pine Contorta, arguing that it was Contorta when he planted it and he assumed it still was the same! He was always conscious of the long term consequences of decisions and tried to predict the interest of future generations. He was cautious in planning and pondered how to approach a decision whose consequences could be irreversible.

He published several articles in Irish Forestry, he wrote about Cloosh forest in Vol. 13, No 2 (1956) and on the wood ant (Formica rufra) in Vol. 23, No 2 (1967). He organised several field trips in the West for the Society and during these memorable outings he would draw attention to the many features and landscapes that moulded and influenced his path in life. Tomás attended his last field day in 2002 in counties Galway and Mayo. This was on the occasion of the 60th anniversary of the founding of the Society.

Bhí suim mhór ag Tomás i nGaeilge agus bhí an leagan Gaeilge dá ainm cláraithe sa Roinn i 1946. Thóg sé fein, agus a bheanchéile Noreen, arb as an nGaeltacht di, a chlann go hiomlán leis an nGaeilge. Ina theannta sin bhain sé feidhm as an teanga oiread agus ar fhéidir le linn dó bheith i mbun a oibre.

Tomás was a deeply religious man and a lifelong teetotaller. At his funeral the coffin was draped with the flag of The Pioneer Total Abstinence Association (PTAA) in recognition of his lifelong membership and advocacy.

Tomás was predeceased by two of his sons Kieran and Finian. To his wife Noreen and family Gearóidín, Ailish, Emer, Cathal, Bláth, Fergal, Annin, Sinéad, Tom and Doireann we offer our sincere sympathy.

"Ar dheis Dé go raibh a anam dílis."

Frank Nugent

Denis O'Sullivan
1948-2014

The death of Denis O'Sullivan at Marymount Hospice in Cork on 17th November 2014, although expected, came as a shock to the forestry community around the country. A man so full of life and "Kerry" joie de vivre - it was hard to believe that he had passed away.

Denis was born the eldest of nine children to Jeremiah and Eileen (née Brennan) on 1st June 1948 at Ohermong Cross, near Cahersiveen on the Ring of Kerry.

He received his early education at Knockeens National School, a hotbed of Renard GAA - a club of which he was later to become Chairman. Denis received the remainder of his primary education and all of his secondary education at Cahersiveen CBS.

He began his forestry career at Kinnitty Castle Forestry College in September 1966 and on qualifying in 1969 he was appointed as an assistant forester in Cong Sawmill, Co. Mayo.

Like others of his generation Denis endured many transfers during a short period of time. In 1970 he moved to Lough Atorick, Co. Clare; 1971 saw him in Cappamore, Co. Limerick; in 1973 he was transferred to Slievenamon Forest, Co. Tipperary; in 1975 to Brosna, Co. Kerry and in 1978 he was transferred to Ballyhooley, Co. Cork before moving to the Limerick Region and finally back to South Kerry.

When he returned to Cahersiveen, Denis threw himself wholeheartedly into community development. His efforts culminated in the development of a fine marina and the restoration of the disused RIC barracks as a tourism resource. He realised that emigration had drained the locality of its young people for generations and he was willing to take practical steps to reverse the trend.

Denis also built up a sizable forest estate of his own and a thriving forestry consultancy business. He was a lifelong member and an enthusiastic supporter of the Society of Irish Foresters. He was also a leading member of Association of Irish Forestry Consultants. Denis believed in the importance of continuously upgrading and improving his knowledge of forestry through attending courses, field days and seminars around Ireland. He travelled widely with fellow Society members on study tours to most European countries, America, Canada and South Africa in order to see best international forestry practice and to bring home new ideas to implement here. It is fair to say that his rambunctious nature made for some memorable tours but his absence was also immediately apparent to participants.

Denis was an excellent forester and he loved his work. He excelled in establishing and managing plantations. Indeed many of the young plantations around Kerry are the result of his dedication and hard work. Denis was a pioneer in private forestry. Prior to the early 1980s there were practically no privately owned forests and Denis was one of these rare foresters whose energy, knowledge and enthusiasm could convince farmers and other land owners that forestry was a good investment for them.

Denis had a huge presence wherever he was. He loved to question and challenge authority and was not afraid to express his own opinion on any topic in his own unique style, but afterwards he would laugh about it. Denis was a character in his own way and he was great for the banter and enjoyed it equally as much when he was on the receiving end of it.

Denis had a way of meeting people, of connecting with people and in gaining their trust and loyalty. He worked with many farmers, contractors, forestry officials and others in planting land, constructing forest roads and thinning their plantations. He was an achiever, he got things done. He was the person you went to if you wanted a job done – whether it concerned his own profession as a forester, the GAA or his work in the community in Cahersiveen.

He was predeceased by his brother Michael in 1990. To his wife Mary and children Donogh, Dermot, Norma, Rory, Thelma and Bronagh, his brothers Diarmuid, Patrick, John T., sisters Mary, Nora, Bridget and Eileen we offer our deepest sympathy.

"Ar dheis Dé go raibh a anam dílis."

Seán Galvin

Niall OCarroll
1934 – 2015

The death has occurred of Niall OCarroll in his 81st year. As a forester he played a leading role in Irish forestry from the time he entered the Forestry Division of the Department of Lands in 1957 until his retirement in 1995. As a young forester in the organisation he pioneered procedures for scientific field research which would become established practice. Later, as Chief Inspector of the Forest Service, he was involved in the process leading to the formation of Coillte, the semi-state forestry company for the management of a timber resource which he had helped to establish. On his retirement he retained a strong interest in state forestry. His frequent letters to the Editor of the Irish Times were influential in shaping public opinion whenever the publicly owned forests were threatened with sale or acquisition by another body.

Niall was born in Athlone into a musical family whose influence would remain with him all his life. He received his primary and secondary education locally. When it came to a choice of career he could hardly ignore the fact that two of his first cousins, Joe and Tom, were serving forest officers in the state Forest Service. He entered UCD to study forestry in 1951, graduating with 1st Class honours in 1956, and went on to take a Masters degree. He completed his practical year in Ballygar Forest, Co. Galway under the tutelage of Harry Silke, Head Forester. His experience there gave him an insight into what it meant to be a forest worker and he would often refer to them as the real creators of our national forests.

On graduation, he secured a teaching position at Johnstown Castle, which was then the headquarters for the Soils Section of the Agriculture Institute (now Teagasc). In 1957, he accepted a position in the then Forestry Division of the Department of Lands and was assigned to the newly formed Research Branch with responsibility for research into forest crop nutrition. The poor quality of soils which formed the major part of the expanded forestry programme of the 1950s required soil amelioration of some form or another and nutrient input. Niall's task was to determine what was needed to support productive forest growth. His approach was based on scientific experimental design, using replicated field trials, something of a novelty at the time. This soon became standard practice across Research Branch and was bolstered by a course, instigated by Niall, on statistics and experimental design at the Dublin Institute of Technology. The success of the experimental approach he advocated and practiced, led him to a number of important discoveries, including unravelling the essential role of potassium in forest growth in the Midlands, and the cause of group dying disease in conifers. Both of these findings were implemented in practice and this led to healthier and more productive forests. His scientific approach became the standard practice in forest research and subsequently led to a series of findings by Research Branch. These form the basis for the establishment, species composition and management of many Irish forests up to the present day. Indeed the productive nature of Irish forests owes a lot to Niall's approach and leadership.

In 1972 he was awarded a PhD for his work on tree nutrition by the National University of Ireland.

Promotion took him away from research for a period but he returned there as Senior Inspector (Research) in 1979. In 1982, he took over the duties of Assistant Chief Inspector, and was promoted to Chief Inspector of the Forest Service in 1986. He retired in 1995.

Although he had often said that he would retire to the west of Ireland, many colleagues were much surprised when he did relocate to Ballinrobe, Co. Mayo. An inveterate bibliophile, even from his student days, he set about converting an outbuilding into a library to house his book collection. This he continued to build on with purchases on the Internet, many of them rare books of forestry interest. He also found time to write: he is the author of 'Forestry in Ireland – A Concise History' and co-author of 'Sitka spruce in Ireland'. The former is dedicated: *To the memory of those who worked hard for little reward and less thanks to create the asset we all now enjoy* – a fitting tribute to the hardy forest workers. He had many publications on tree nutrition to his name both as author and co-author and he edited the revised edition of 'The Forests of Ireland', which was published by the Society of Irish Foresters. Under the pen-name Wood Kerne he contributed forestry related articles of literary interest to Irish Forestry for many years. These articles, gleaned from his extensive library, were first choice reading for many.

He was a lifelong member of the Society of Irish Foresters on which he served as Editor, continuously from 1969 to 1977. He was President from 1983 to 1985 and was elected an Honorary Member in 2006.

Niall had a love of Irish music and was an accomplished uillean piper. He was passionate about state forestry. The associated principle of sustainability of wood supply and services was his creed, and one he adhered to throughout his professional career. He would remind those who would listen, that sustainability in forestry had its origins in the early 18th century and that, as foresters, we had a moral obligation to leave to future generations something more than depleted forest resources.

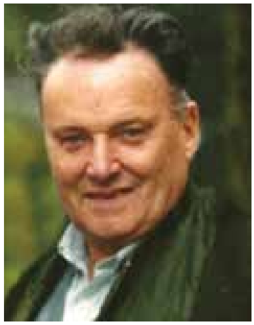
Niall was a highly principled individual, never prepared to compromise. This trait often led to disagreement with those who viewed forestry as too long term an enterprise as well as colleagues who saw it as a resource to be exploited for short-term gain.

He was laid to rest among the Partry hills in west Mayo, not too far from Nephin and Glenamoy, where he conducted some of his seminal field work many years ago.

He is survived by his wife, Theresa, children Cormac, Aoife, Derval, Eadaoin, Ellen, Art and grandchildren, to whom we offer our deepest sympathy.

P.M. Joyce

Brendan J. Collins
1929 - 2015



Brendan Collins passed away peacefully on 2nd March 2015 in his 87th year. He was born on 9 February 1929 to Patrick, a Department of Agriculture employee and Delia (nee Marren) in Ballymote, Co. Sligo. He received his primary and secondary education in Ballymote. Prior to commencing his studies at Avondale he attended Pallaskenry and Athenry Agricultural Colleges.

Brendan began his forestry career at Avondale Forestry School in November 1950 and when he graduated in 1953 he was appointed an assistant forester in Dungarvan, Co. Waterford. This was followed by a sojourn in Emo, Co. Laois before taking up the management of a newly created forest at Castledaly, Co. Galway in the summer of 1956. Writing in "A Social History of Forestry in Ireland" which was published in 2000 by Crainn Publications, Brendan describes in admirable detail the official opening of the new forest at Castledaly. The opening ceremony was attended by several dignitaries including the Minister for Lands, Joe Blowick and the then Bishop of Galway, Dr Browne. There was a reception afterwards in Glynn's Hotel in nearby Gort. It is a testament to Brendan's humanity that, writing this article almost 50 years later, he still bemoaned the fact that the two local foresters, Tom Cox and Tom Finnegan, had not been invited to this reception. H.J. Gray, the Establishment Officer, apologised to both men afterwards explaining that it was due to an oversight on his part. (For the benefit of our younger readers, the Establishment Officer was the precursor of the Personnel Officer, who later metamorphosed into today's Human Resource Manager).

The early 1950s were hungry days and rural employment was scarce and eagerly sought after. Brendan describes how he initially hired five workers from the Employment Exchange in Gort to begin the large planting programme at Castledaly. However, on the following Monday morning twelve extra men turned up seeking work - such was the hunger for steady employment in rural areas at that time. The disappointed newcomers became aggressive and Brendan was forced to cancel operations for the day. The following day an even larger group of 25 men arrived at the forest gate, all demanding work on the planting site! However, over time Brendan was able to employ more and more men and eventually built up a proud team of well trained forestry workers in Castledaly. In 1961, Brendan was transferred to Killeshandra, Co. Cavan and while there he was instrumental in establishing Killykeen Forest Park.

In 1969 Brendan was conferred with the National Diploma in Forestry (NDF), one of the few people in the Republic of Ireland to achieve this distinction. The National

Diploma in Forestry was awarded by the Central Forestry Examination Board of the United Kingdom and was taught in Forestry Commission schools. Holders of the NDF were accepted as qualifying for Associate Membership of the Institute of Chartered Foresters.

Brendan was soon promoted to the post of Assistant District Inspector in Portlaoise where he worked with John O'Connell. Both of these fine foresters strove wholeheartedly to promote the professional management and development of forests in the Slieve Bloom Mountains and their efforts have bequeathed us some of the finest and most productive forests in the country. After a sojourn of nine years Brendan was transferred on promotion to Galway city to the post of Work Study Inspector. He had a particular interest in Method Study as it applied to forest operations and while in Galway he played a major role in the computerisation of the accounting system in the Galway Division. When Coillte was set up in January 1989, Brendan became the Regional Accountant in Galway and worked in this capacity until his retirement on 31st January 1993. This final move was a convincing testament of his flexibility and adaptability in a fast changing work environment.

The enthusiasm and zeal which Brendan displayed throughout his career was a wonderful example to the many young foresters and forest workers who came in contact with him over the course of his long career. Above all else, Brendan was a man of the highest integrity who was respected by, and respectful of, all he encountered. He was always good company and, while most conscientious about the job at hand, the rigours of many a long working day had their lighter moments which Brendan would punctuate with a good hearty laugh. Brendan was a great family man and his passing leaves this world a lesser place for all who knew him, but especially for his family whom he adored.

He had a lifelong interest in trees and forestry education. In 1975, he visited Sequoia National Park in California and his subsequent report was published in *Irish Forestry, Vol. 32 No. 2, 1975*. After his retirement in 1993, Brendan dedicated much of his time to voluntary roles in both the Active Retirement Association and Parish Social Club, but it was in his beloved garden that he spent many happy hours honing and refining his encyclopaedic knowledge of horticulture and silviculture. Brendan maintained a keen interest in the Society of Irish Foresters and all things to do with forestry until he passed away peacefully earlier this year.

To his wife Mary, his daughters Majella, Hilary, Maura and Barbara, his son Pat, sisters Fidelma and Carmel and brother Dermot we offer our sincere sympathy.

"Ar dheis Dé go raibh a anam dílis."

Tom Kavanagh

Denis Michael O'Sullivan
1916 – 2015

On 19th March 2015 Dinny passed away, in his 99th year, and is buried in his adopted county of Sligo. Denis Michael (Dinny) O'Sullivan was born on 1st October 1916 at Kilcrea, Ovens, Co. Cork, the youngest of four siblings to Denis and Nora (née McNamara).

After his primary education at the local National School in Ovens he attended the Sacred Heart and Presentation Colleges in Cork city. Then via a scholarship to Clonakilty Agricultural College in 1937, whence he progressed to study forestry at Avondale in 1938.

On qualifying in 1941, he was assigned to Kilsheelan Forest and later to Nire Valley Forest. In 1945, he became Forest Manager at Killakee Forest in the foothills of the Dublin Mountains, followed by postings to Tuamgreaney, Athlone and Ballymahon Forests. In 1956, he transferred as a Grade 1 Forester to manage Ballyhoura Forest.

He was promoted to the Inspectorate in 1961 as Assistant District Inspector in Sligo. In 1968 he was promoted District Inspector, Cavan, where he replaced Fergal Mulloy who transferred to the newly created Wildlife Section at HQ, in preparation for European Conservation Year 1970. As a District Inspector, he was a keen advocate of multiple use forest management – not only for timber production but also conservation, wildlife and recreation. In 1971, Dinny had his last official transfer to become District Inspector, Carrick-on-Shannon, based at Lough Key Forest Park. He retired on 1st January 1982, having given 45 years sterling service to Irish forestry.

Throughout his long professional career, he was recognised as a shrewd manager of forest, financial and human resources and spoke the language of commerce and business long before it became fashionable in state forestry circles. Always an active and keen member of the Society of Irish Foresters, he led a number of field days over the years – see *Irish Forestry,* Vol VIII, 1951.

During the 1950s, he was a busy and energetic General Secretary of the State Foresters Association. His crowning achievement was the enactment of legislation in 1954 which gave foresters, for the first time, permanent and pensionable status as civil servants. Previously, foresters had been employed on a temporary, fulltime basis with no permanence of employment or pension entitlements. For this monumental achievement, we foresters owe him a huge debt of gratitude.

Throughout his life, Dinny was an ardent GAA man, both on and off the playing field where he won five county championship medals in hurling and football in counties Wicklow, Westmeath and Waterford. A founding member, and later vice-president, of St. Mary's GAA Club in Sligo town, his forte was the encouragement of young "townies" to play Gaelic games, giving rise to a famous phrase of his – "keep them in sport and out of court". This encouragement of youth was further expressed by his involvement with *Scór na nÓg*, travelling with competitors to many national venues.

In retirement, he remained active, pursuing his interest in gardening and the growing of vegetables, flowers and plants and the maintenance of St. Mary's GAA grounds. He and Kay polished up their dance steps and tripped the light fantastic on many a ballroom floor throughout the North West. He also developed a penchant for sun holidays and lazy days on Mediterranean beaches with the occasional sangria and sing-song.

Dinny was a Gael in the best sense of that word. He had a wonderful appreciation and love of the Irish language, history, poetry, song, our heritage and the beauty of the native landscape and countryside.

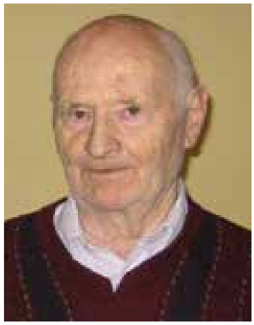
At his funeral his long life was fully celebrated and culminated with the singing by family and friends of *An Chualann* at his graveside, followed by a lusty rendition of *The Bould Thady Quill*, which was composed by a cousin of his grandfather – Johnny Tom Gleeson.

To his wife, Kay and children, Denis, Mary, Nora and John we offer our sincere sympathy.

"Sursum Corda."

Tony Mannion

Tadgh (Tim Joe) Collins
1929-2015



Tadgh Collins passed away peacefully on 12th May 2015 in his home of many years at "Iveragh" in Tullamore, Co. Offaly, during the course of his 86th year.

He was born on 5th February 1929 in Lisnagat just north of Bandon, Co. Cork to John and Mary (nee Griffin). He was the second oldest of a family of two brothers, Sean and Denis, and three sisters, Monica, Mary and Philomena. He received his primary education at Mount Pleasant National School and later went on to secondary education in Bandon. Tadgh attended Clonakilty Agricultural College on a scholarship from 1946 to 1947 and then attended the Albert College, Dublin from 1947 to 1948 also on a scholarship.

He studied forestry at Avondale Forestry College, Co. Wicklow from 1949-1952. On completion of his studies there Tadgh was appointed forester at Ballygar Forest, Co. Galway. He subsequently transferred to Killakee Forest, Co. Dublin. In 1959 he transferred to Tullamore Forest, Co. Offaly as Forester-in-Charge and he remained there until his retirement in February 1994 having reached retirement age. Subsequent to the establishment of Coillte in January, 1989 Tadgh was appointed a Territorial Forester in November 1990. Tadgh joined the Society of Irish Foresters away back in June 1955 and he remained a loyal life-long member and supporter of the Society. He regularly attended our field days and in later years travelled with Society members on our study tours to several countries throughout Europe. He made a host of new friends on these study tours abroad as he was extremely good company during these expeditions.

I first met Tadgh back in 1989. At that time a large area of Bord na Móna cut over bog land had become available for planting and several large sections of this land were attached to Tullamore Forest. I was working in nearby Kinnitty Forest back then and was assigned to assist Tadgh with the initial phase of planting these newly acquired lands. I still carry many pleasant memories of those early days. I remember Tadgh's great enthusiasm for this huge planting project. In particular, I can recall being very impressed by the speed with which he could traverse those bogs on foot while I struggled to keep pace with him! In subsequent years I enjoyed sharing many journeys with Tadgh as we travelling together to attend District events, Society field days, union meetings and even international study tours.

Following Tadgh's retirement in late 1990, his "old forest" area eventually came under my stewardship. In subsequent years, I frequently had cause to revert to Tadgh and tap into his expertise to resolve some seemingly intractable "local issues". On these occasions Tadgh's local knowledge and broad silvicultural expertise were always freely and generously forthcoming. Invariably his advice was exactly what the situation required, but I never received an Invoice for "consultancy fees" …… a pleasant reminder of a now vanished Ireland.

Tadgh was essentially a shy man who was happier to remain in the background. Nevertheless, he was a most effective forest manager. Like many foresters of his era, he brought great integrity, coupled with frugality in the expenditure of public money, into all forest operations he engaged in. The valuable forest estate we have inherited is a fine testament to their success, since it was put in place with the minimum expenditure of public funds.

His wife Dolores predeceased him. To his sons Brendan and Finbarr and his daughter Aedín we offer our sincere sympathies.

"Ar dheis Dé go raibh a anam dílis."

Richard Jack