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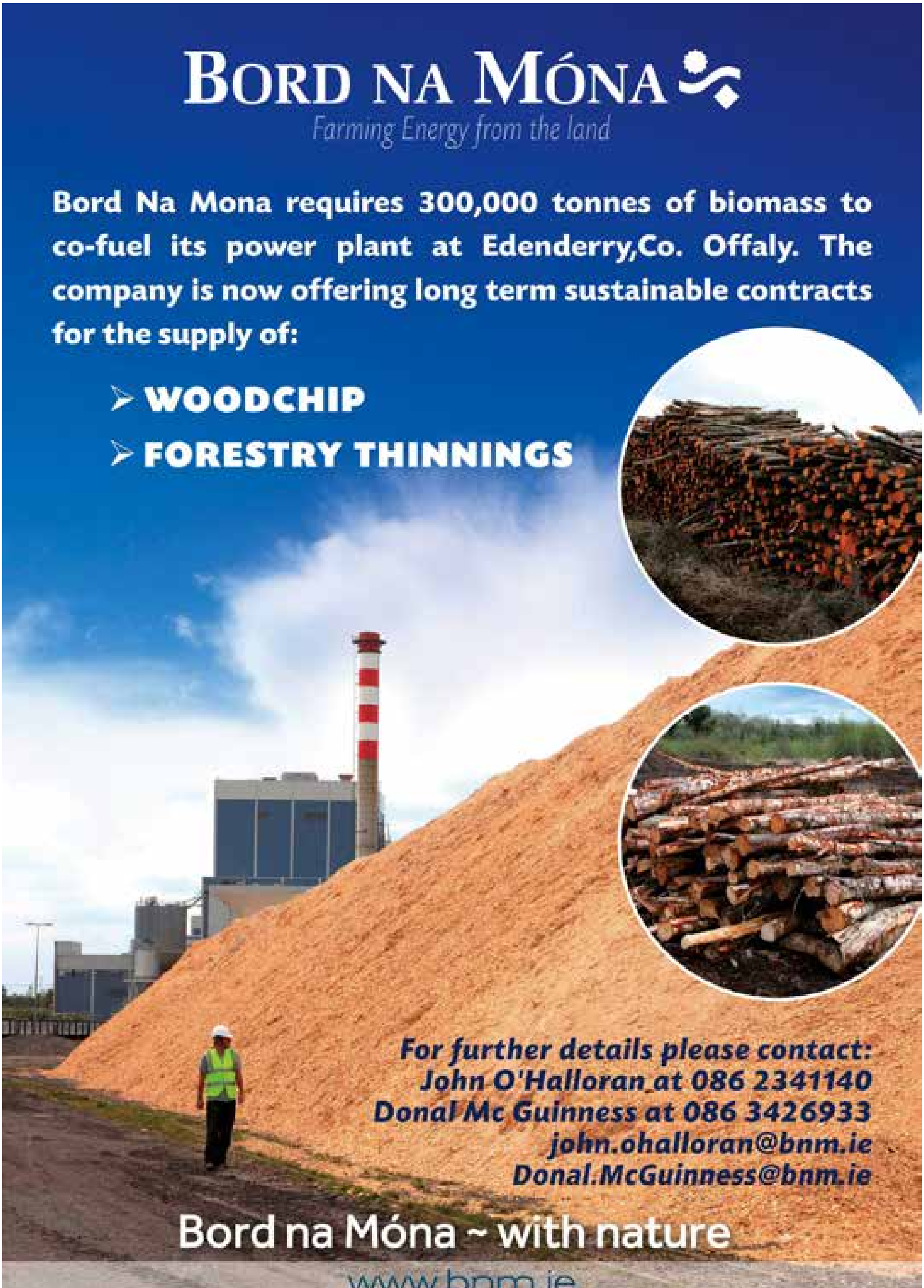

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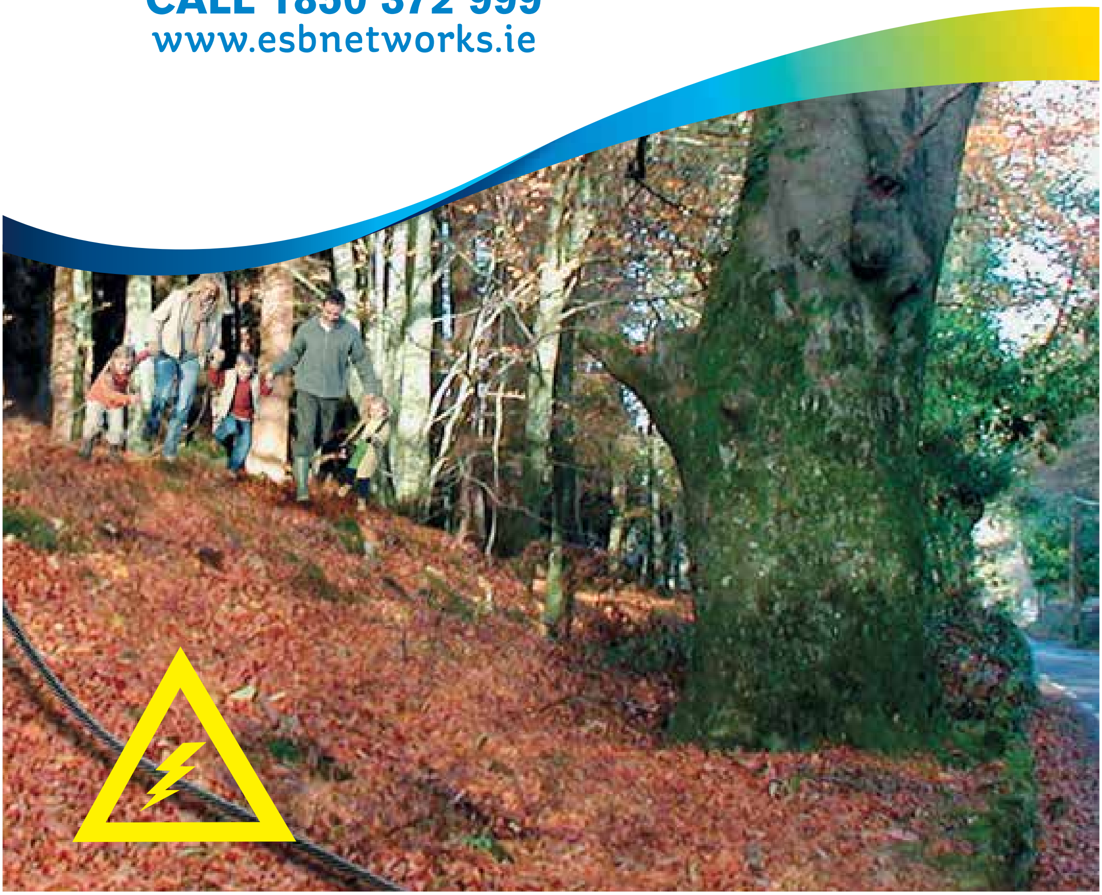


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- To support professionalism in forestry practice and help members achieve their career goals.
- To establish, secure and monitor standards in forestry education and professional practice.
- To foster a greater unity and sense of cohesion among members and provide an appropriate range of services to members.

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1. Original material only, unpublished elsewhere, will be considered for publication in *Irish Forestry*. Where material has been submitted for publication elsewhere, authors must indicate the journal and the date of submission.
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Front cover: Looking upwards at the canopy of a Sitka spruce stand in Baunreagh in the Sliabh Bloom mountains (Photograph: Brian Tobin).

Acknowledgements
The Editors would like to thank the anonymous reviewers who have contributed considerably to maintaining the quality of the scientific and other articles published here. The assistance of Kevin Hutchinson and John Mc Loughlin in organising the book reviews has resulted in a very vibrant section over the last number of issues and is much appreciated.

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EDITORIAL

As above, so below

As above, so below,
as within, so without,
as the universe, so the soul…

Hermes Trismegistus

I remember visiting a forest stand as a student with Professor Gardiner. The theme was silviculture and in response to whatever searching question we were posed, there were many blank looks and much staring at the trunks in front of us. "Look up, look up, a forester should always look up first," was the exasperated refrain we were treated to. Wisdom can take time to settle in the minds of students, but "looking up" seems such an obvious perspective now. However, in the early days a question about timber production seemed naturally to draw our eyes to the stems rather than the photosynthetic sails aloft, busily harnessing what light was available to drive productivity. The fact that most plant species on this island are light-limited should be constantly to the fore while considering the silvicultural options available in striving to meet the multiple objectives that are now demanded of our forest stands.

Silviculture, the core discipline of forestry, is reasserting its importance. In light of the alarming example of how easily and quickly ash may be removed from our forests, allowing the national forest estate to become more dependent on a single species, even one as dependable and robust as Sitka spruce, is unacceptable. The obvious way to change this situation is to plant a more diverse range of species. This in turn, will test our ability to more actively and specifically manage the resulting forest stands. Perhaps in the past we may have been lulled into relying too heavily on the considerable abilities of Sitka spruce to accommodate great variations in site quality and, at times, questionable management decisions. The practice of progressive silviculture in Ireland is currently hampered to some considerable extent by the rigidity of the Afforestation Scheme and its Grant Premium Categories (GPCs) which guide plantation designs along the *safest* route. The significant financial penalties imposed by the Forest Service in the last few years means that it is safer to plant blocks of Sitka spruce than to attempt a more innovative approach (which might result in a penalty or require additional financial inputs to qualify for final grant payment). Such a conservative policy will only serve to increase the risk posed by potential pest or diseases, or indeed from climate change, and certainly will not increase the afforestation area. Perhaps we should pluck a leaf from progressive corporate culture

(Deloitte, Forbes, Google, Apple, MS, etc.) where policy is often not to punish, and even sometimes to reward, failed innovation, so long as a clear rationale was provided. This fosters a progressive and innovative culture within the company. Could the grant-aided Irish forestry sector take on such an ideal?

An example of the restriction imposed by the afforestation GPCs is the limited scope for planting broadleaf mixtures. To date this has resulted in the large monocultural blocks of ash that are now of such uncertain fate. Unless foresters are allowed to practice their profession fully and develop planting and management schemes entirely of their own design (obviously within best practice guidelines), without the threat of draconian penalties when these prescriptions don't work out as planned, the situation will not be remedied. Greater flexibility would surely foster innovation, learning, enthusiasm, partnership (from both public and private sectors) and support the true concept of sustainable forest management. Is this not the best way to create multifunctional forests which can provision multiple ecosystem services and, critically, build and increase the resilience of the entire industry?

A basic requirement is the widening of the approved species list, particularly in view of the increased threats to our forest resource and the ongoing loss of species from the list. At first glance it is disappointing that the approved list of grant-aided species is somewhat limited, however, it is heartening that the Forest Service intimates that it will consider proposals to use species not mentioned on the list.

The theme of silvicultural development is accorded considerable presence in this issue of *Irish Forestry*. Hawe and Short present an in-depth and extensive review of examples of European broadleaf silviculture which are of relevance to Ireland. Providing a focused development to this theme, Fennessy et al. describe a variation of traditional French silviculture which aims to produce high quality oak lumber from substantially shortened rotations. They combine this with a report on trials of "free grown" oak in the UK. Both these articles provide abundant food to inspire innovative silviculture as well as enlightened stewardship. So much for the "carrot" approach. An article by McInerney et al., which describes a remote sensing method of assessing the forest damage wreaked by Storm Darwin, serves as a striking reminder of why it doesn't pay to keep all one's eggs in one basket. Adding to this timely warning is a letter from the only practicing forest pathologist on this island, who makes some useful suggestions on protecting forest and plant health on the island of Ireland. De Miguel-Muñoz et al. explore the reaction of the wood processing sector to an alternative silvicultural system for producing biomass. Also from WIT, Coates et al. make a comparison between various machine methods for harvesting biomass. Interestingly, there are three articles describing ecosystem service provision in Irish forestry: Bullock et al. review the extent and value of such services, Griffin details Coillte's progress in providing and protecting such services, while Iwata et al.

investigate and discuss the health benefits of visiting and spending time in forests.

The Forest Perspectives section features several interesting articles; for example, Forrest describes the history of ceremonial tree planting at Áras an Uachtaráin, while Mc Loughlin investigates the etymology of Irish placenames associated with trees. And lest any reader fears or imagines any lack of interest for Sitka spruce-philes, a burgeoning Book Review section holds among its nine reviews, a gem entitled *Shades of Green, An Environmental and Cultural History of Sitka Spruce* by Tittensor. It is reassuring to note from the extensive list of recent publications, the obvious continuing interest in the printed word. Equally reassuring is the reappearance of the Letters to the Editor section. The second of two letters in this section makes a case for more enlightened stewardship in assessing actual site suitability as well as the true environmental benefit of forestry

Of course, the building of resilience in this sector will depend on the ingenuity and novel approaches of its personnel, a cornerstone of which will be to increase the numbers of high calibre students. However, in order to attract them, all those working in or sharing an interest in Irish forestry have a job to do to change and ameliorate the public perception of forestry "and all that therein is".

Deforestation in Ireland 2000 – 2012

John L. Devaney[a, b*], John J. Redmond[c], Grace M. Cott[a, b] and John O'Halloran[a]

Abstract

Although Ireland's national forest area continues to expand, recent evidence has suggested that the gross annual rate of deforestation is also increasing. Heretofore, no spatially explicit characterisation of contemporary deforestation areas in Ireland exists. Given uncertainties associated with current deforestation estimates, investigation of new methodologies is required to inform future land-use change accounting approaches. This paper presents a summary of the DEFORMAP project, which investigated the extent and nature of deforestation in Ireland for the 2000 – 2012 period. A combination of high resolution aerial photography, satellite imagery and ancillary datasets was used to quantify forest loss in the Republic of Ireland. In total, 5,457 ha of deforested land was identified which, following accuracy assessment, was error-adjusted to 7,465 ±785 ha. The error-adjusted gross annual national deforestation rate for the period of study was 0.103%. The deforestation rate increased from the first time interval investigated (2000-2005) to the second (2005-2010), followed by a reduction during the 2010 – 2012 period. High inter-county variation in gross annual deforestation was identified, with the highest level of deforestation occurring in Co. Monaghan (0.25% yr^{-1}) and the lowest in Co. Limerick (0.02% yr^{-1}). Principal post-deforestation land-use transitions were to agricultural grassland, built-land and wetland. Patterns of post-deforestation land-use transitions varied widely between counties indicating changing regional pressures on forest land. This paper presents an important development in our understanding of contemporary land-use change in Ireland by developing the first national deforestation map. The Deforestation Map presented here will provide a valuable record of forest loss, which can be used to validate any future earth observation based deforestation monitoring approaches, such as automated radar remote sensing techniques.

Keywords: *Deforestation, Ireland, UNFCCC, National Forest Inventory, Land-use change.*

Introduction

Ireland's afforestation programme has rapidly increased forest cover from <1% at the turn of the 20th century (Mitchell 2000) to now almost 11% (Forest Service 2013). Indeed, forest policy in Ireland targets an increase of national forest cover to 18% by 2046 (Forest Service 2014). While the extent of forest cover in Ireland continues to expand, recent evidence from Ireland's National Forest Inventory (NFI) suggests that the gross annual deforestation rate may also be increasing (Forest Service 2013, Forest Service 2007).

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As a net carbon sink, Ireland's forests make a significant contribution to national greenhouse gas reduction targets (Byrne 2011). Since its establishment in 1994, the United Nations Framework Convention on Climate Change (UNFCCC) has required Annex 1 Parties to provide an annual inventory of afforestation, reforestation and deforestation areas. NFI information is a key component of deforestation reporting under the Land-Use, Land-Use Change and Forestry (LULUCF) sector of Ireland's National Inventory Report (NIR) on greenhouse gas emissions to the UNFCCC. As part of the NFI, over 1,800 permanent sample forest plots are resampled on a periodic basis and their land-use is determined by ground survey and imagery interpretation. However, for countries where deforestation is a relatively rare event, area estimates based on this methodology can be associated with high levels of uncertainty (Dymond et al. 2008). In Ireland for example, for the period 2000 – 2006, the total NFI derived national deforestation area estimate (±95% confidence intervals) was 6,000 ha ± 3,000 ha (Forest Service 2007). Other existing deforestation data, such as limited felling licence records, are subject to errors as no unlicensed or exempted deforestation activities are accounted for.

In Ireland, for NFI and other national and international deforestation reporting, the UNFCCC definition of deforestation is adopted i.e. "the direct human-induced conversion of forested land to non-forested land" (Penman et al. 2003). Hence, as long as replanting occurs within a five-year period, forest management operations such as clear-felling, do not constitute deforestation. Features that form part of forest infrastructure, such as forest roads, are considered part of forest land-use and are not deemed deforestation activities. Examples of deforestation (permanent land-use changes) include the construction of windfarm infrastructure, motorways, housing settlements on forest land, and the conversion of forest to agricultural uses.

Given the uncertainty associated with current deforestation estimates, investigation of new methodologies is required to inform future land-use change accounting approaches. Heretofore, no spatially explicit characterisation of contemporary deforestation areas in Ireland exists. To address this knowledge gap, in 2012 the DEFORMAP (Deforestation Estimation and Mapping in Ireland) project was initiated. This project set out to characterise the nature and extent of contemporary deforestation in Ireland. A combination of high resolution aerial photography, satellite imagery and ancillary datasets has been used to provide a spatially explicit map of deforestation in Ireland for the period 2000 – 2012. This paper presents a summary of the findings of the DEFORMAP project. Particular emphasis is placed on the rate of gross annual deforestation per county, land-use transitions and forest type and ownership.

Materials and methods

Using a combination of available records of deforestation in Ireland and interpretation of imagery, a national deforestation map for the 2000 – 2012 was created, hereafter termed the Deforestation Map. The process by which this map was created is outlined below and in Figure 1. Throughout, the forest definition used for UNFCCC reporting in Ireland was applied, i.e. land with a minimum area of 0.1 ha, trees >5 m in height and canopy cover ≥20% (or the potential to reach those thresholds *in situ*) (Duffy et al. 2014).

Photointerpretation

Wall-to-wall manual photointerpretation of high-resolution aerial imagery was carried out for the Republic of Ireland. Three series of orthorectified aerial photography were available: Ordnance Survey Ireland (OSI) 2000, 2005 and 2010 orthophotos at a scale of 1:40,000 and pixel size of 1 m. National scale

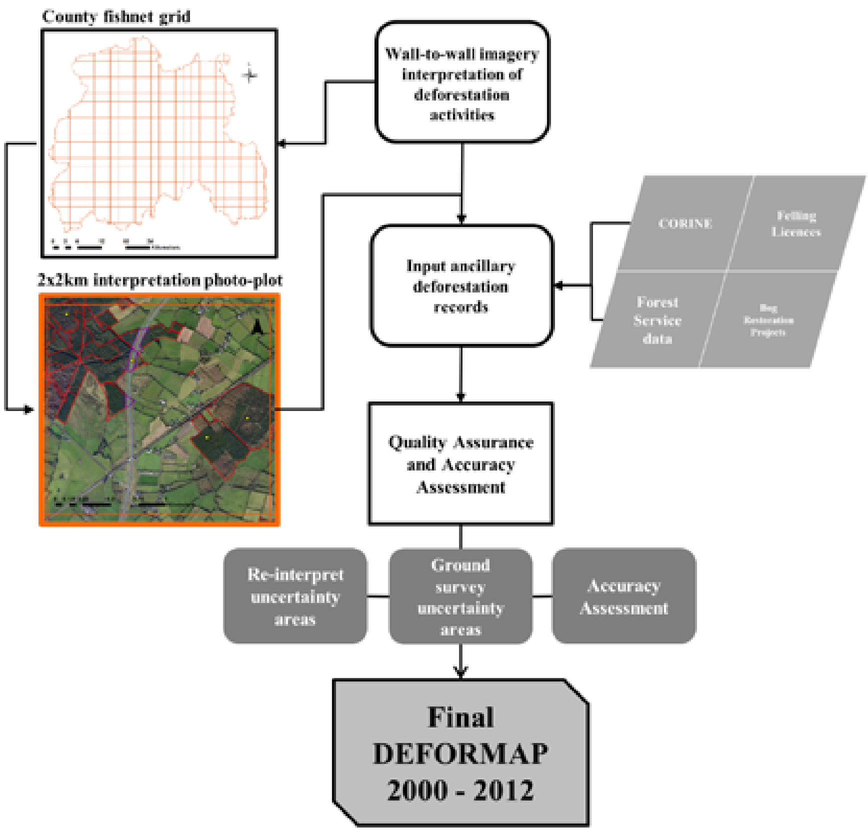

Figure 1: *Production flow chart of the Deforestation Map.*

high resolution (<1 m) aerial imagery, captured between November 2011 and May 2012, was also obtained through the Bing Maps base layer function in the geographic information system (GIS) software ArcGIS 10.2. A "fishnet" grid was used to create interpretable 2 × 2 km photointerpretation "photo-plots" (Figure 1). In total, 18,889 photo-plots were interpreted at a scale of 1:8,500. Hence, imagery for the entire land mass of the Republic of Ireland was analysed. A time-series visual assessment of geo-rectified imagery for each photo-plot was carried out to identify any deforestation events during three time intervals: 2000 – 2005, 2005 – 2010 and 2010 – 2012. A deforestation event was defined as any area where a clear land-use transition (LUT) from forest to non-forest land-use had occurred. Two existing forest vector datasets were used to aid interpretation: (1) the most recent Forest Service national forest cover map (Forestry 2012) and (2) the Irish National Survey of Native Woodland (Perrin et al. 2008) spatial dataset of native woodlands in Ireland. The spatial extent of each deforestation event was digitised and a suite of attributes was recorded including forest type, age, ownership, and land-use transition (LUT). Categories of forest type were conifer (at least 81% canopy cover of coniferous trees), broadleaf (at least 81% canopy cover of broadleaf trees), and mixed (broadleaved and conifer species, the minor category making up at least 20% of the canopy). Categories of forest age were <20 years, 20 – 40 years and >40 years. Categories of ownership were private grant aided, private non grant-aided and state established. The term "state established" was applied to forests that were planted by the state but may have been sold into private ownership prior to deforestation activity. Examples included the construction of windfarms on former state owned forest land. Recording of LUTs were based on a modified version of NFI land-use reporting categories, namely grassland, wetland, built land rural, built land urban, windfarm, road, green space, quarry, peat, cropland and other.

Ancillary records

A number of pre-existing sources of information describing the deforestation area are available for the Republic of Ireland for the study period. These records were used to identify additional deforestation areas not initially captured during the photointerpretation process.

<u>CORINE</u>

The European Commission and European Environmental Agency established the CORINE programme in 1985 with the aim of providing land-cover information for Europe (Bossard et al. 2000). Based on interpretation of satellite imagery, pan-European datasets of classified land-cover types are available for 1990 (CORINE land cover (CLC) 1990), 2000 (CLC 2000), 2006 (CLC 2006) and 2012 (CLC 2012). For this study, datasets describing differences between the CLC 2000 - 2006 and the CLC 2006 – 2012 imagery were used to identify areas changing from forest to non-forest land-use during the study periods. Each CORINE polygon identified as potentially changed was validated using contemporary OSI and Bing Maps high resolution aerial imagery. Where the spatial extent of CORINE derived deforestation differed, or where no deforestation activity was evident based on imagery, CORINE deforestation polygons were modified or excluded from the dataset.

Felling licences

In the Republic of Ireland, the Forestry Act of 1946 legally requires land owners to obtain consent for the majority of deforestation activities in the form of Limited Felling Licences (LFLs). The regulation of the felling licences is the reponsibility of the Forest Service Division within the Department of Agriculture, Food and the Marine. Certain deforestation activities do not require a felling licence, such as public road building or the felling of trees to facilitate the distribution of electricity. Since 2007, records of these LFLs contain information regarding the area and location of deforested land. Afforested areas less than 10 years old are exempt from LFL requirement for deforestation activities. However, most forest areas less than 10 years-old are subject to grant and premium payments under a national afforestation scheme. In such cases, forest owners are obliged to notify the Forest Service if these areas are removed from forest land-use. Since 2007, the Forest Service maintained records of lands taken out (known as LTOs) of forest land-use. For this study, the spatial extent of LFL and LTO deforested areas in the study regions were digitised in ArcGIS 10.2 based on hard-copy maps provided in licence applications. As with CORINE data, where the spatial extent of deforestation differed based on imagery interpretation, deforestation polygons were modified or removed.

Bog restoration

From 2002 to 2008, Coillte Teoranta (the semi-state forestry company) and various other agencies undertook large-scale raised and blanket bog habitat restoration projects under the European Union LIFE funding mechanism. Spatial information on restoration activities in the study regions involving the conversion of forest land-use to wetland (bog/heath) land-use was obtained from Coillte Teoranta.

Other data sources

Periodic updates to the Forest Service national forest cover map (Forestry 2012) were made throughout the study period. Therefore, information on potential deforestation areas was available by extracting forest areas that were present in previous national forest cover datasets but absent in Forestry 2012. These areas were examined using imagery to verify deforestation activity and determine the LUT. In addition, results from the most recent NFI indicated a large proportion of deforestation area coming from forest areas clear-felled and not replanted within a five-year period. Supplementary data on these potential deforestation areas was obtained through the Forestry 2012 dataset. Using land-cover attributes in Forestry 2012, areas listed as forest in 2000, clear-felled in 2005, and remaining clear-felled in 2010 and 2012 were extracted. Due to difficulties differentiating clear-felled areas from recently replanted forest using imagery, all such areas were ground surveyed to verify current land-use. The full extent of deforestation events highlighted by the NFI was also digitised in ArcGIS 10.2 based on the most recent imagery.

The Deforestation Map

Deforestation areas based on the above sources were appended to the photointerpretation dataset to create the Deforestation Map, a geodatabase of deforestation events in Ireland for the 2000 to 2012 period. In cases where the occurrence of deforestation or LUT was uncertain, polygons were reviewed by other expert photo-interpreters. Where uncertainty remained following re-interpretation, ground surveys were carried out. In total, 233 sites were ground surveyed to verify deforestation activity (Figure 2). To test classification accuracies, a stratified random sample of deforestation polygons was selected and information such as forest age, type and land-use transition were cross-checked by an independent analyst to determine the percentage agreement in the attributes assigned. Overall, percentage agreement varied from 80% for the forest age category to 96% for the forest ownership category. An accuracy assessment of deforestation areas was carried out using imagery point sampling and ground survey plots. The Irish national forest vector dataset (Forest2000) was used as reference data for forest land-use area for the year 2000. Within Forest2000, 7,936 stratified randomly located points were visually interpreted using Google Earth imagery, which was used as a reference for 2012 land-use (sampling was restricted to areas where post 2011 imagery was available in Google Earth). Areas where a clear, permanent, non-forest land-use was evident in 2012 were recorded as deforestation. LUCAS (Land Use/Cover Area frame Survey) plots (n = 219) and NFI forest plots (n = 1,845) were added to the accuracy assessment dataset (total n = 10,000). Following comparison between the Deforestation Map and the reference dataset, the producer's accuracy (the proportion of deforested points based on the reference data that is also mapped as deforestation), user's accuracy (the proportion of the area mapped as deforestation that is actually deforested based on reference data) and overall accuracy (the proportion of the area mapped correctly) were calculated. For uncertainty analysis, the 95% confidence interval of the error-adjusted deforestation area estimate was calculated following Olofsson et al. (2013).

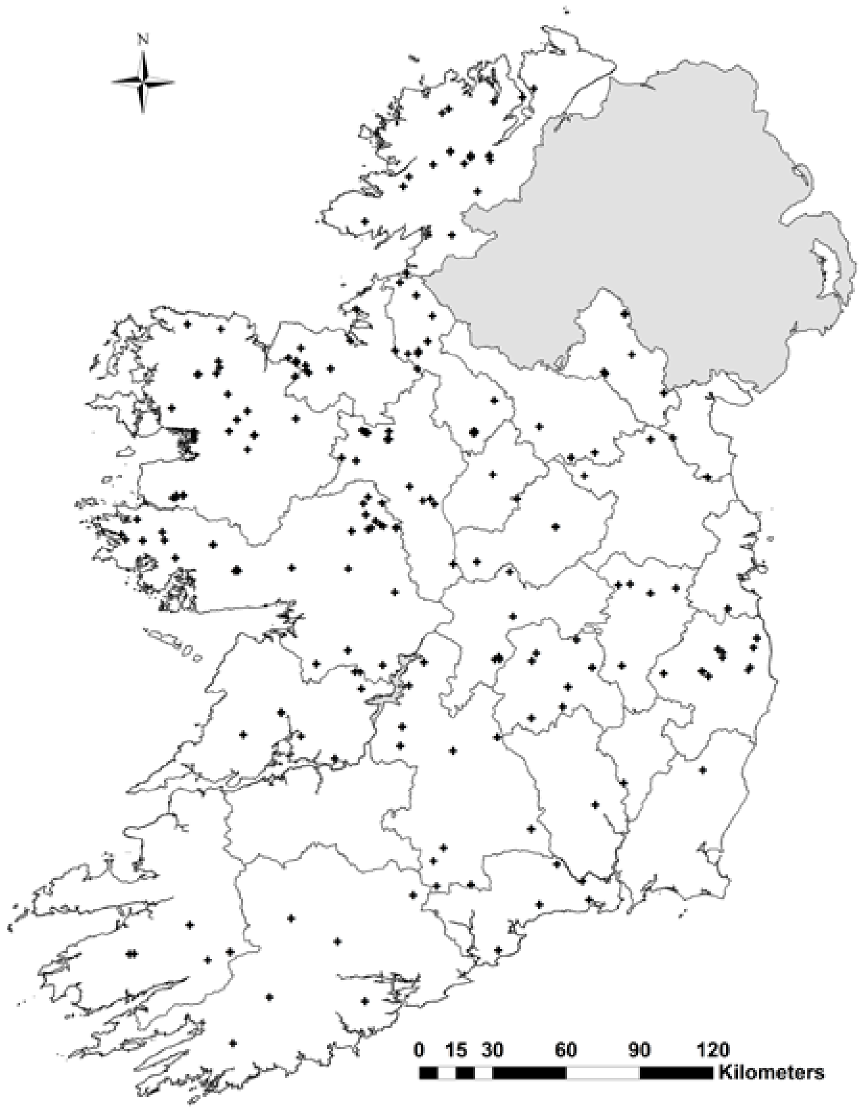

Figure 2: *Spatial distribution of 233 ground survey sites used to validate deforestation events.*

Results

In total, 5,457.1 ha of land deforested during the 2000 – 2012 period were explicitly identified (Table 1). The counties with the highest total area of deforestation for the period were Galway (1,008.5 ha) and Mayo (809.1 ha). These counties had approximately twice the area of deforested land in comparison to the next highest county (Cork: 443.1 ha; Table 1). In contrast, the counties with the lowest total deforestation

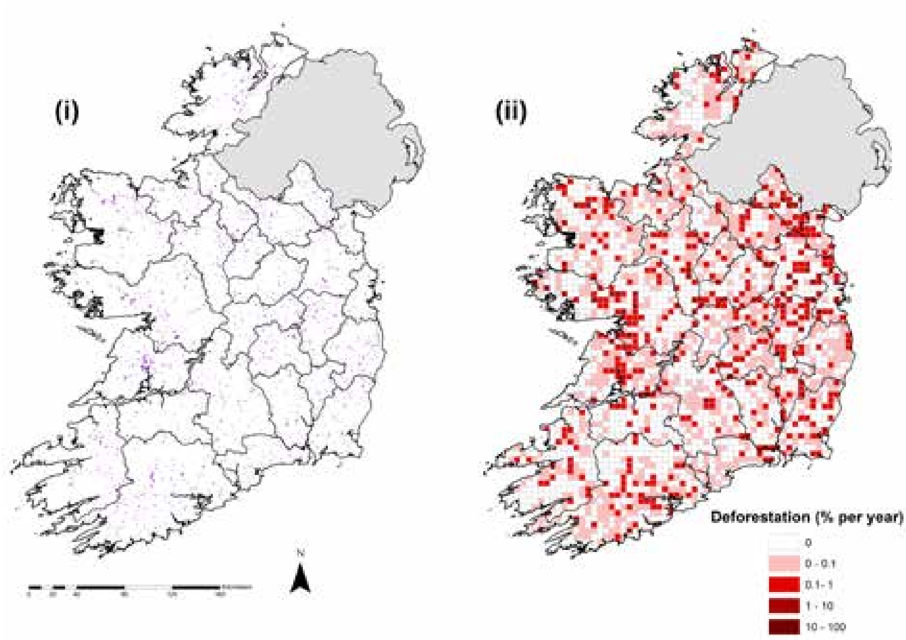

Figure 3: *(i) The Deforestation Map indicating the spatial distribution of deforestation events during the period 2000 – 2012 (areas are slightly exaggerated for visual purposes) and (ii) the gross annual deforestation rate on a 5 × 5 km grid. White indicates squares with no deforestation.*

area were Longford (28.6 ha) and Dublin (31.9 ha). Relative to the existing area of forest in the county, Monaghan and Louth had the highest level of deforestation with gross annual deforestation rates of 0.248% and 0.243% respectively. Limerick and Longford had the lowest rates of gross annual deforestation, 0.022% and 0.029% respectively (Table 1). The gross annual national deforestation rate for Ireland for the 2000 – 2012 period was 0.075%. The national average size of deforestation event was 1.81 ha, however this varied widely between counties. For example, the mean size of deforestation events in Mayo was 3.97 ha, whereas in Longford, it was only 0.73 ha (Table 1). Nationally, the median size of deforestation event was just 0.62 ha.

As shown by the Deforestation Map (Figure 3 (i)), the occurrence of deforestation events was relatively evenly distributed across the Irish landscape. As expected, areas of a high density of deforestation events were associated with areas of high forest cover. Figure 3 (ii) displays the gross annual deforestation rate throughout the country on 5 × 5 km grid. Based on this map, some clusters of high deforestation areas are visible, such as central Clare and the Louth-Monaghan border regions.

The overall temporal trend in deforestation area was an increase from the 2000 – 2005 period (415.5 ha yr^{-1}) to the 2005 – 2010 period (565.6 ha yr^{-1}) followed by a decline in deforestation for the 2010 – 2012 period (350.9 ha yr^{-1}). However, variation between counties was evident; in Monaghan deforestation decreased from 20.3 ha yr^{-1} in the 2000 – 2005 period to 5.2 ha yr^{-1} in the 2005 – 2010 period and increased to 19.4 ha yr^{-1} in the 2010 – 2012 (Table 1). Overall, the cumulative deforestation area during the 2000 - 2012 period was minimal in comparison to the cumulative afforestation area for the same period (Figure 4).

In terms of total area, forest to grassland (30.1%) and forest to wetland (27.9%) were the most common deforestation LUTs, each accounting for more than double the next most common deforestation LUT (built land rural: 13.1%; Figure 5)). Built land categories included all human settlement excluding windfarms, roads, recreational green spaces and quarries. Examples of built land transitions included housing developments, water treatment works and landfill sites. Combined, built land rural and built land urban transitions accounted for 14.4% of deforested land. Conversion of forest to cropland was negligible, accounting for only 0.24% of the total deforestation area (Figure 5).

Almost half of the total deforested area occurred in state established forests (2,757.2 ha), with the majority of this taking place in conifer dominated forests (Figure 6). Deforestation area of broadleaf dominated state established forests was only 27.7 ha. The extent of deforestation, which occurred in privately owned forests that were established with some form of grant aid was smaller (1,122.5 ha). Within this, 730.7 ha occurred in conifer dominated forests, 229 ha in broadleaf

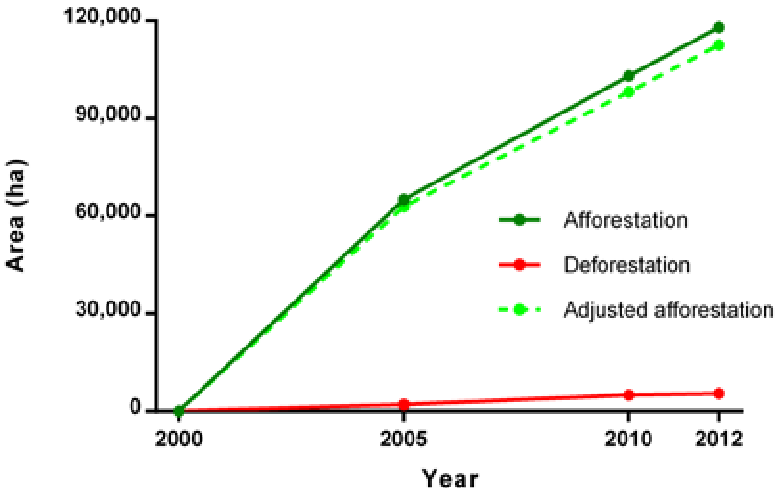

Figure 4: *Cumulative afforestation, deforestation and adjusted afforestation (the afforested area minus the area of deforested land; ha) in the Republic of Ireland for the period 2000 – 2012.*

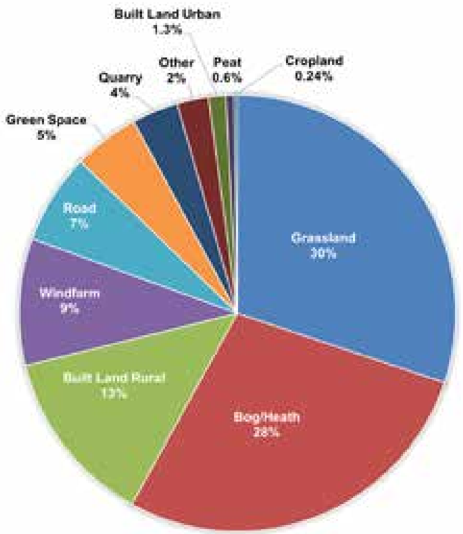

Figure 5: *Proportional area of post deforestation land uses.*

dominated forests and 162.8 ha in mixed forests. During the study period, 1,566.9 ha of deforestation took place on privately owned non-grant aided forests and, the majority of this occurred in broadleaf dominated forests (1,284.5 ha) (Figure 6).

An error-adjusted change area and associated confidence intervals were calculated for the Deforestation Map based on the error matrix following the methods outlined in Olofsson et al. (2013). The accuracy assessment revealed significant errors of omission (27%) but few errors of commission (2.5%), resulting in an error-adjustment of total deforestation area from 5,457.1 ha to 7,465 ±785 ha. The error-adjusted gross annual national deforestation rate for Ireland for the 2000 – 2012 period was 0.103 %.

Discussion

As Ireland's national forest area continues to increase, so does the need to develop national forest monitoring capabilities. In this study, novel and existing records of deforestation activities were combined with high-resolution imagery interpretation to quantify loss in forest land-use in Ireland for the period 2000 – 2012. This paper presents an important development in our understanding of contemporary land-use change in Ireland; the first spatially explicit national characterisation of deforestation areas.

Temporal and spatial patterns in deforestation

Nationally, a relatively stable annual deforestation rate was recorded throughout

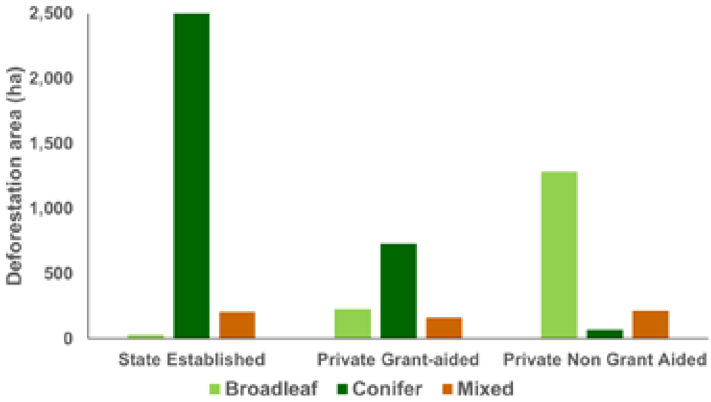

Figure 6: *Deforestation area (ha) from different forest type (broadleaf, conifer and mixed) and ownership (state established, private grant-aided and private non grant-aided) categories.*

the study period (Table 1 and Figure 4). The increase in the national deforestation rate from the 2000 – 2005 to the 2005 – 2010 period was related to large-scale bog restoration programmes, carried out by Coillte Teoranta and other agencies. Raised and blanket bog habitat restoration activities included the clear-felling of coniferous forest and conversion to their pre-afforestation land-cover of bog/heath. Although some felling operations took place pre-2005, an increase in forest to wetland conversions occurred for the 2005 – 2010 period. These restoration programmes had a significant influence on the overall findings of the study, particularly for attributes such as the average size of deforestation event and deforested land ownership. Compared to other recorded events, bog restoration deforestation areas were large (>30 ha). Exclusion of bog restoration areas from the Deforestation Map dataset would result in a reduction in the national average size of deforestation event from 1.81 ha to 1.51 ha. Omitting bog restoration areas from the analysis would reduce the proportion of "state established" forests from 50% to 34% of the total deforestation area.

A high proportion of the deforestation area was attributable to broadleaf forests in non-grant aided private ownership (Figure 6). Broadleaf forests constitute 25% of the national forest area and semi-natural broadleaf forests constitute only 2% of the national forest area (Forest Service 2013, Perrin et al. 2008). Sixty percent of deforested non grant-aided privately owned broadleaf forests were converted to agricultural grassland (Devaney et al. unpublished data). From a conservation perspective, the high rate of deforestation of broadleaf forests is unexpected and has implications, particularly in the context of habitat protection legislation such

Table 1: *Details of deforestation area (ha yr^{-1}), rate (%) and mean size of event (ha) in Ireland (per county) for the period 2000 – 2012.*

County	Total deforestation area (ha)	Deforestation area (ha) 2000 - 2005 (ha yr^{-1})	2005 - 2010 (ha yr^{-1})	2010 - 2012 (ha yr^{-1})	Gross annual rate (%)	Mean area of event (ha)
Leitrim	97.6	1.2	9.6	21.7	0.031	1.22
Longford	28.6	2.0	2.4	3.4	0.029	0.73
Meath	140.9	2.8	23.1	5.8	0.094	1.57
Louth	70.9	2.9	8.4	6.9	0.243	1.07
Cavan	105.5	3.0	17.3	2.1	0.052	0.90
Dublin	31.9	3.7	2.6	0.0	0.051	1.33
Carlow	58.4	3.7	7.0	2.4	0.058	1.22
Offaly	102.4	4.6	14.6	3.3	0.035	1.11
Limerick	70.3	4.8	5.6	9.2	0.022	1.03
Westmeath	109.0	5.1	15.7	2.6	0.069	1.65
Sligo	119.1	6.6	8.1	22.7	0.048	1.59
Laois	126.5	8.1	15.2	4.9	0.042	1.32
Roscommon	174.5	8.6	22.0	10.6	0.056	2.05
Wicklow	183.8	9.7	23.8	8.1	0.043	1.63
Tipperary	172.6	10.8	19.4	86.3	0.030	1.11
Waterford	94.8	10.8	7.1	2.7	0.030	1.30
Kilkenny	114.7	11.3	10.4	3.2	0.050	2.12
Donegal	207.2	11.7	27.2	6.5	0.031	0.89
Wexford	150.0	14.2	11.9	9.8	0.090	1.44
Kildare	215.1	19.8	16.1	17.7	0.172	2.33
Monaghan	166.6	20.3	5.2	19.4	0.248	1.63
Kerry	274.7	26.8	14.4	34.2	0.043	1.68
Cork	443.1	39.4	40.2	22.5	0.044	1.65
Clare	381.2	39.5	32.4	10.8	0.061	1.69
Mayo	809.1	68.8	84.4	21.5	0.130	3.97
Galway	1,008.5	75.2	121.6	12.3	0.141	3.63
Total	5,457.1	415.5	565.6	350.9	0.075	1.81

as the EU Habitats Directive and agri-environment schemes such as the Rural Environmental Protection Scheme. Given that broadleaf forests often occur on mineral soil types, which are conducive to agricultural production, it is likely that these areas are at a higher risk of deforestation to grassland.

An increase in conversions from forest to "built land rural" also occurred between the 2000 – 2005 period and the 2005 – 2010 period, followed by a sharp decline for 2010 – 2012 (Figure 7). During the 2000 – 2007 period, Ireland's flourishing economy was associated with an increase in the construction of private housing, commercial property and public infrastructure. Although development peaked in 2007, high levels of construction continued into 2009 (Kitchin et al. 2014). However, the well documented financial crash and economic decline led to a downturn in the construction sector (Whyte et al. 2013) which is reflected in a reduction in the conversion of forest land to built land rural for the same time period.

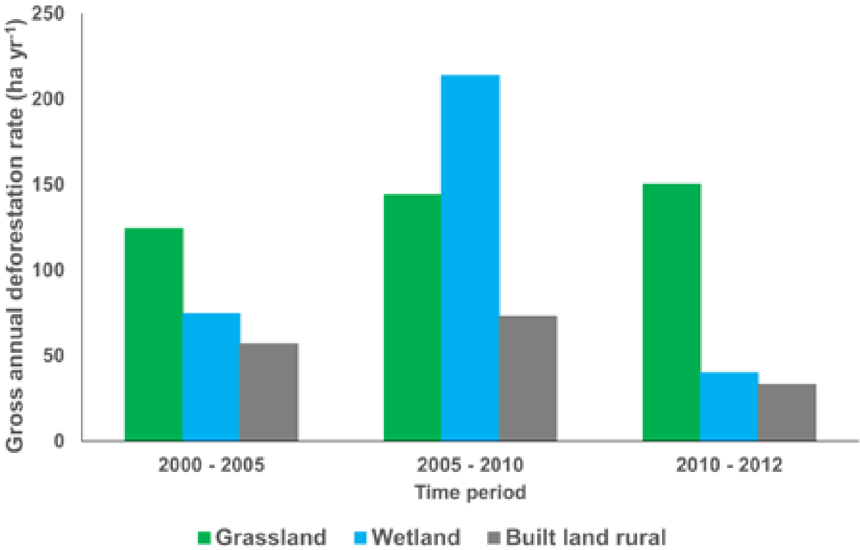

Figure 7: *Gross annual deforestation rate (ha yr^{-1}) for the three principal post deforestation land-use categories (grassland, wetland and built land rural) for three time periods (2000 – 2005, 2005 – 2010, 2010 – 2012).*

High inter-county variation in the rate of forest loss indicates changing spatial and temporal pressures on forest land-use. For example, in Donegal, 32% of the total deforestation area was attributable to conversions to built land, with 18% attributable to forest-grassland LUTs. In Laois, only 12% of deforestation was associated with conversion to built land with forest-grassland being the principal land-use transition (51%). Regional clusters of deforestation activities were evident, including areas surrounding Ennis, Co. Clare and on the Louth – Monaghan border. Deforestation activities in both these areas principally involved the conversion of forest to grassland. Spatial patterns of forest land-use changes are likely to reflect regional variation in factors such as economic development and productivity of agricultural land. The Deforestation Map geodatabase facilitates the assessment of regional influences on forest land-use change events. Further research is required to investigate the regional drivers of deforestation and to develop tools that may predict future deforestation hot spots such as in De la Heras et al. (2012) and Sanchez-Cuervo et al. (2013).

Comparison with National Forest Inventory estimates

For the 2000 – 2012 period, a total of 5,457.1 ha of deforested land were identified by this study. This figure is substantially less than the 15,600 ha ± 4,931 ha of deforested land estimated by the NFI for the same period (Forest Service 2013, Forest Service 2007), which is significant in the context of UNFCCC reporting. Currently, post 2000 deforestation area reported in Ireland's UNFCCC National Inventory Report is based on changes in land-use of NFI permanent sample plots. Although this approach is used in many countries (Tomppo et al. 2010), for countries where the deforestation rate is low (<1%), small sample sizes may result in high levels of uncertainty associated with estimates (Dymond et al. 2008, Magnussen et al. 2005). The large uncertainty associated with Ireland's NFI deforestation estimates is due to the low incidence of deforestation in the sample plots (0.8 - 1.3%) (Forest Service 2013). The benefit of applying a "wall-to-wall" approach presented here is that a map accuracy assessment can be carried out using standard methods. The accuracy assessment of the Deforestation Map indicted that the overall accuracy was 98% and the error of omission (the proportion of deforested points in the reference data that are not actually mapped as deforestation) was 27%. When an error-adjusted Deforestation Map area (7,465.63 ±785.67 ha) is applied, the estimate remains below the minimum area confidence interval of the NFI (what is NFI) estimate, indicating that NFI derived data over-estimates national deforestation area. The use of other national deforestation statistics from sources such as limited felling licences are likely to underestimate deforestation areas as unlicensed activities are unaccounted for. Levy and Milne (2004) concluded that in Britain, deforestation estimates based on felling licences most likely represented a minimum, as unlicensed felling also occurred but to an unknown extent. Inconsistencies between the Deforestation Map, NFI estimates and national deforestation statistics, though expected, nevertheless highlight the need for a modified national deforestation accounting approach.

Future deforestation monitoring in Ireland

For the purposes of UNFCCC reporting, updates of national deforestation areas would be challenging using the Deforestation Map approach due to the low temporal availability of high resolution imagery and resource constraints relating to time intensive wall-to-wall manual photo-interpretation (Devaney et al. 2015a). Nonetheless, a national scale photointerpretation of deforestation areas could potentially be repeated on a cyclical basis using updated national imagery datasets. Still, remote sensing is an effective tool for monitoring forest area changes in an objective and transparent way (McInerney et al. 2011). Due to developments in technical capabilities, the use of high resolution satellite-based optical remote sensing is now well established in operational forest monitoring systems worldwide, e.g. India (Forest Service of India 2004), Brazil (INPE 2013) and New Zealand

(Dymond et al. 2012). However, the application of optical remote sensing is limited in countries such as Ireland, which have near-constant cloud coverage. Microwave remote sensing systems however are not as influenced by atmospheric conditions and may be more appropriate for tracking Irish landscape changes (Barrett et al. 2014, Devaney et al. 2015b). The national Deforestation Map will provide a valuable record of forest loss, which can be used to validate any future remote sensing deforestation monitoring approaches. Ultimately, as UNFCCC reporting is on the basis of land-use and not land-cover, a combination of remotely sensed information and ground-based observations is the most practicable approach in determining deforestation areas and associate land-use transitions.

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References

Barrett, B., Nitze, I., Green, S. and Cawkwell, F. 2014. Assessment of multi-temporal, multi-sensor radar and ancillary spatial data for grasslands monitoring in Ireland using machine learning approaches. *Remote Sensing of Environment* 152: 109–124.

Bossard, M., Feranec, J. and Otahel, J. 2000. *CORINE land cover technical guide: Addendum 2000*. European Environment Agency, Copenhagen.

Byrne, K. 2011. The role of plantation forestry in Ireland in the mitigation of greenhouse gas emissions. *Irish Forestry* 67: 86–96.

de las Heras, A., Lake, I.R., Lovett, A. and Peres, C. 2012. Future deforestation drivers in an Amazonian ranching frontier. *Journal of Land Use Science* 7: 365–393.

Devaney, J., Redmond, J. and O'Halloran, J. 2015. Contemporary forest loss in Ireland; quantifying rare deforestation events in a fragmented forest landscape. *Applied Geography* 63: 346–356.

Devaney, J., Barrett, B., Barrett, F., Redmond., J. and O'Halloran, J. 2015. Forest cover estimation in ireland using radar remote sensing: a comparative analysis of forest cover assessment methodologies. *PloS ONE*, 10, e133583.

Duffy, P., Hanley, E., Hyde, B., Ponzi, J., O'Brien, P., Cotter, E., and Black, K. 2014. *Ireland National Inventory Report 2014*, Greenhouse Gas Emissions 1990–2012. Reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency, Wexford, Ireland.

Dymond, J.R., Shepherd, J.D., Arnold, G.C. and Trotter, C.M. 2008. Estimating area of forest change by random sampling of change strata mapped using satellite imagery. *Forest Science* 54: 475–480.

Dymond, J.R., Shepherd, J.D., Newsome, P.F., Gapare, N., Burgess, D.W. and Watt, P. 2012. Remote sensing of land-use change for Kyoto Protocol reporting: the New Zealand case. *Environmental Science and Policy* 16: 1–8.

Forest Service of India. 2004. *State of Forest Report 2003*. Ministry of Environment and Forest, Dehra Dun, India.

Forest Service. 2007. *National Forest Inventory Republic of Ireland – Results*. Department of Agriculture, Food and the Marine, Johnstown Castle, Wexford, Ireland.

Forest Service. 2013. *Ireland's National Forest Inventory Results 2012*. Department of Agriculture, Food and the Marine, Johnstown Castle, Co. Wexford, Ireland.

Forest Service. 2014. *Forests, Products and People. Ireland's Forest Policy – a Renewed Vision*. Available at https://www.agriculture.gov.ie/media/migration/forestry/forestpolicyreviewforestsproductsandpeople/00487%20Forestry%20Review%20-%20web%2022.7.14.pdf [Retrieved April 2014].

Gallagher, G., Dunne, S., Jordan, P. and Stanley, B. 2001. *Ireland's Forest Inventory and Planning System*. Forest Service, Department of Agriculture and Food, Johnstown castle Estate, Co. Wexford. Ireland.

INPE. 2013 *Monitoramento da Floresta Amazônica brasileira por satélite*. Instituto Nacional de Pesquisas Espaciais Projeto Prodes. Available at http://www.obt.inpe.br/prodes/index.php [Retrieved October 2013].

Kitchin, R., O'Callaghan, C. and Gleeson, J. 2014. The new ruins of Ireland? Unfinished estates in the post-Celtic Tiger era. *International Journal of Urban and Regional Research* 38: 1069–1080.

Levy, P. and Milne, R. 2004. Estimation of deforestation rates in Great Britain. *Forestry* 77: 9–16.

Magnussen, S., Kurz, W., Leckie, D.G. and Paradine, D. 2005. Adaptive cluster sampling for estimation of deforestation rates. *European Journal of Forest Research* 124: 207–220.

McInerney, D., Suarez, J. and Nieuwenhuis, M. 2011. Extending forest inventories and monitoring programmes using remote sensing: a review. *Irish Forestry* 68: 6–22.

Mitchell, F. 2000. The development of Ireland's tree cover over the millennia. *Irish Forestry* 57: 38–46.

Olofsson, P., Foody, G.M., Stehman, S.V. and Woodcock, C.E. 2013. Making better use of accuracy data in land change studies: estimating accuracy and area and quantifying uncertainty using stratified estimation. *Remote Sensing of Environment* 129: 122–131.

Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R, Buendia, L., Miwa, K., Ngara, T., Tanabe, K. and Wagner, F. (Eds). 2003. *Good practice guidance for land use, land-use change and forestry*. Institute for Global Environmental Strategies. Hayama, Japan.

Perrin, P., Martin, J., Barron, S., O'Neill, F., McNutt, K. and Delaney, A. 2008. *National Survey of Native Woodlands 2003–2008: Volume I: Main report*. National Parks and Wildlife Service, Dublin.

Sanchez-Cuervo, A.M. and Aide, T.M. 2013. Identifying hotspots of deforestation and reforestation in Colombia (2001–2010): implications for protected areas. *Ecosphere* 4: art143.

Tomppo, E., Gschwantner, M., Lawrence, M. and McRoberts, R.E. 2010. *National Forest Inventories Pathways for Common Reporting*. Springer: Dordrecht.

Whyte, K., Daly, H.E. and Ó Gallachóir, B.P. 2013. Modelling HGV freight transport energy demand in Ireland and the impacts of the property construction bubble. *Energy* 50: 245–251.

Broadleaf thinning in Ireland – a review of European silvicultural best practice

Jerry Hawe[a] and Ian Short[b*]

Abstract

A substantial first-rotation broadleaf plantation resource in Ireland is progressively entering a thinning phase. Silvicultural best practice in support of such a management intervention needs to be developed for this new woodland resource to achieve its maximum commercial potential. National research trials are key to the provision of information for the development of best practice. Determining the current state-of-the-art is a prerequisite to the design and implementation of appropriate research trials. This study reviews the literature concerning the fundamental principles of broadleaf thinning with particular regard to timing, intensity and impacts on crop tree growth response, focussing on a range of commonly planted broadleaf species in Ireland. The overall aim of this review is to gain a fuller understanding of the most effective thinning methodology to be employed to maximise the production of high quality hardwood timber. In doing so it is intended that the information presented may support ongoing and future research trials with regard to potential silvicultural treatments to apply, data types and analysis and the likely results of practical application to commercial forestry.

Keywords: *Silviculture, selective thinning, thinning intensity, thinning control.*

Introduction

Ireland has a stocked forest area of 637,140 ha (DAFM 2013); of this area, broadleaved species account for 164,310 ha. Of those broadleaves, 33.9% are effectively non-commercial species (both long and short living), of which over half are willow (*Salix* spp.). The next largest broadleaf species group comprises birch (*Betula* spp.; 22.7%), followed by ash (*Fraxinus excelsior* L.; 12.5%) and oak (*Quercus* spp.; 10.2%) (DAFM 2015). Just over 74% (c. 122,246 ha) of the broadleaved area is under 30 years of age. The vast majority of this new, first rotation, plantation resource was established with State aid under the Afforestation Scheme. Since state support for forestry development in the private sector began, about 60,000 ha of new broadleaved plantation have been established in Ireland (Hendrick and Nevins 2003, DAFM 2012). Broadleaved planting has increased dramatically since 1993, with ash as the single most prevalent species (DAFM 2013, 2015). The most recent figures place ash afforestation at 17,000 ha since 1990 (DAFM 2015). The stand configuration of the four main commercial hardwood species tends to be in either single species blocks (ash and sycamore (*Acer pseudoplatanus* L.)) or intimate line mixtures (oak and beech (*Fagus sylvatica* L.)) (DCMNR 2000).

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The silviculture of these new forests now comprises not only establishment and tending phases, but increasingly, as the resource matures, an early thinning phase. Thinning should aim to add value to the initial State investment by maximising the production of high quality hardwood timber. In 2009 a tending and thinning element of the Forest Improvement Scheme was introduced. This provides grant aid for the first thinning of broadleaved plantations. Of the new broadleaf plantation resource, 4,760 ha has been thinned up to the end of 2014 and ash has been the main species treated (DAFM 2015). Given the overall figures outlined above, it would appear that only a proportion of those crops requiring first thinning are actually being treated.

Much remains to be understood concerning the most appropriate silvicultural thinning practices in first rotation Irish broadleaf plantations. Even-aged, greenfield plantations comprised, at least initially, of single main crop species, may be an appropriate foundation in the development of a new broadleaf woodland resource. However, they do present quite unique management challenges (Hawe and Short 2012) and opportunities, which require that existing technical guidelines and academic knowledge be reviewed against the particular environmental and structural context specific to Irish plantations. For example, similar to the coniferous forest resource, Irish broadleaved stands, under certain favourable growing conditions, have proved to be very vigorous - perhaps more so than the same species in the UK or continental Europe. This has implications with regard to the timing and intensity of thinning treatments, as well as how they might be adapted from UK or European standard practice in order to take advantage of this opportunity to harvest an increased yield. European, British and Irish forests in general face an increased risk from pests and disease (Pautasso et al. 2015), not least young, even-aged, monocultural plantations of ash in Ireland. This may also drive the need to maintain crop trees in the best possible health and vigour and grow them as quickly as possible to maximise yield for securing returns on the initial capital investment. This situation may also require the development of adapted thinning treatments. Adapted thinning treatments may form the basis of structural and species diversification in order to build resilience and secure ecological objectives for our broadleaf woodland resource. However, for any such adapted thinning treatments to be designed and applied, first an appropriate baseline for conventional thinning in Irish broadleaf plantations needs to be established. This study seeks to inform that process. As and when the most effective and practical early thinning prescriptions are established, they can be disseminated to Irish forest owners and managers. This may help to facilitate the transition from the "farmer who owns a forestry plantation" to "farm forester," who is actively involved in the management of their plantation. Engaging and informing forest owners should help to address the apparent shortfall in the timely first thinning of existing broadleaved crops in Ireland.

This paper reviews established UK and Irish broadleaved silviculture texts, being based on similar environmental and stand conditions, in an attempt to synthesise best-practice relating to the early thinning of pole-stage plantations. The paper also reviews the findings from contemporary European, UK and Irish silvicultural research trials on selected broadleaf species that are of relevance to Irish plantation forestry. The overall aim of this review is to establish silvicultural best practice with regard to the early thinning treatments applied to the new broadleaf plantation resource in Ireland, with particular regard to the timing of interventions, thinning intensity and impacts on tree crop growth response.

Broadleaf thinning – a general overview

Thinning reduces stand density, competition and affords the remaining trees more space to grow. The primary crop response to thinning relates to the distribution of volume within the stand (Savill et al. 1997). Total volume production per unit area does not differ greatly between thinned and unthinned stands. Provided the site is fully occupied, with a reasonably intact canopy, whereby trees can fully utilise available resources, a stand will produce approximately the same amount of wood at various stocking densities (Zeide 2006). Thinning concentrates this volume on fewer trees, meaning that they produce greater individual volume increment than stands with higher stocking densities (Hamilton 1976, 1981). Different management objectives concerning diameter and mean radial increment result in differences in rotation length, and in the desired number of crop trees per ha at the end of the rotation (Dobrowolska et al. 2011). "Thinning control" seeks to manage the redistribution of volume increment so that selected trees can produce target stem diameters and log lengths within a given timeframe. Thinning control is supported by various data, including crop age, top height, basal area and stocking (stems ha^{-1}). These data inform decisions on timing and intensity of thinning interventions (Rollinson 1988, Edwards and Christie 1981). Achieving a specific top height or basal area threshold is often used as a determinant of the timing for first and subsequent thinnings. Basal area or number of stems per ha may be used to control the proportion of volume or stocking removed (Table 1).

In broadleaved stands thinning generally seeks to improve the quality of the final crop (Savill et al. 1997). Potential crop trees (PCTs) should have good stem form, good vigour, be disease- and damage-free and should be relatively evenly distributed throughout the stand (Short and Radford 2008). PCTs should be selected early, usually at the time of first commercial thinning (Hart 1991) and subsequent thinning operations seek to favour these trees. This represents a fundamental difference to conifer crops where highly systematic thinning generally seeks to maximise stand volume production. In broadleaved stands the overriding importance of stem quality may dictate that some stand volume production be sacrificed to favour the development of selected PCTs, which should maintain well balanced, even crowns (Kerr and Evans

1993). Most broadleaved species, and particularly ash, cherry (*Prunus avium* L.) and birch (*Betula* spp.), require that the crowns are kept free from competition to maintain good form and vigour (Savill 2013), and therefore PCT volume increment. Thinning too heavily however, may have negative effects on both overall volume production and PCT stem quality such as epicormic shoot growth or heavy low side branching (Savill 2003). Broadleaved thinning should therefore seek to achieve a balance whereby the diameter growth of PCTs is maximised without negatively impacting on stem quality. Evans (1984) identifies five silvicultural objectives for broadleaved thinning:

1. to improve stand quality by removing poorly formed and defective trees;
2. to ensure that future increment is concentrated on the best formed trees;
3. to provide more growing space for final crop trees and so to enhance their diameter increment;
4. to ensure satisfactory development of mixed stands and timely removal of nurse or secondary species;
5. to remove trees which are diseased or damaged in other ways.

The factors identified by selected authors as affecting the decision of how and when to first thin common ash are outlined in Table 1. In general, broadleaved crops should undergo first thinning when 8–10 m top height has been achieved. Crops let grow much beyond this stage may develop crown proportions which are too constricted to fully respond to thinning. Late thinning may also expose remaining stems to wind damage. Initial PCT numbers should be two to four times the required number of final crop trees, which is generally between 60–190 stems ha^{-1} (Kerr and Evans 1993).

Given that the overall aim of broadleaved thinning is to favour PCTs, the principal thinning method recommended in Ireland is "selective", whereby a number of co-dominant competitors are removed to free up PCT crowns in a crown thinning. Some systematic early thinning may also be appropriate such as the opening up of access racks, which may involve the removal of between 1 in 7 to 1 in 10 planting lines (Short and Radford 2008). Wolf trees and diseased trees should also be removed in early thinning.

Whether removed systematically (lines/racks) or selectively in terms of PCT competitors, wolves etc., stocking reduction provides a very practical means of thinning control. Stocking reduction can focus on the removal of specific groups or individual trees required to deliver the silvicultural objectives of the operation. The disadvantage of stocking as a control, particularly if trees are removed in the wrong strata (suppressed/sub-dominants), is that stocking density may not correlate closely with required basal area/volume reduction or with reduced competition.

A more objective method to determine both the timing and intensity of thinnings is through the measurement of basal area, which for most broadleaves should be between 20 and 30 m^2 ha^{-1} prior to thinning (Kerr and Evans 1993). Rollinson (1988) provides threshold basal areas by species (for given top heights). Edwards and Christie (1981) provide post-thin target basal areas by species (for given Yield Classes (YC)). Ultimately a range of crop data, such as age, top height, basal area, volume and stocking, may be utilised with a visual assessment of crown and canopy structure to comprehensively control thinning practice.

Particularly in continental Europe, where there is a long history of broadleaved silviculture, target diameter and log quality over a specified rotation length, dictate the timing and intensity of thinning interventions (Hein and Spiecker 2009). Experience combined with contemporary research has created a body of knowledge concerning quite exacting management inputs with known or expected outcomes, and has facilitated the development of quite precise allometric and yield models. Broadleaved plantations in Ireland on the other hand are effectively a "brand new", first rotation resource with no history of silvicultural management. Nevertheless, Irish forestry can aspire to the development of effective broadleaved silviculture best-practice guidelines and sophisticated management objectives. In doing so, Ireland can begin to assess the fundamentals of best-practice based on the European and UK experience.

Review of individual species literature – timing of initial thinning interventions, intensity and impacts on growth

Thinning of ash

Since the inception of the afforestation programme, ash has been the most widely planted broadleaved species (DAFM 2011). Regardless of stem quality issues (Hawe and Short 2012), good vigour is not uncommon. First rotation ash plantations often achieve YC 8–10, resulting in many stands established in the 1990's now requiring first thinning.

Table 1 summarises the factors that affect the decision to implement first thinning in an ash stand. The "trigger" includes stand attributes which may be monitored to a point in the rotation where they reach a threshold which initiates first thinning. "Intensity control" then provides a guideline for the proportion of the standing crop to be removed.

Table 1 shows that:

- first thinning should commence before the crop reaches 10 m top height (albeit Rollinson (1988) provides no threshold basal area at this height);
- threshold basal area should be 18–20 m^2 ha^{-1}; these conditions may be expected before the crop is 15 years old; and
- the height of live crown should not be allowed fall below 33% of overall tree height or 50% of stem height.

The European project FRAXIGEN (2005) recommends thinning from 6–7 m in height. This represents a pre-commercial thinning, which may include stands derived from natural regeneration that are likely to have a much higher initial stocking than plantations. Early, high intensity interventions in highly stocked, naturally regenerated stands are essential for the development of quality PCTs (Rytter and Werner 2007). While such recommendations on naturally regenerated stands are useful, ash stands in Ireland are derived primarily from plantations with very specific and relatively low initial stocking rates (2,500–3,300 stems ha^{-1}). Joyce et al. (1998) also recommend a pre-commercial thinning or tending for ash plantations at a top height of 7–8 m. Aside from the removal of wolves, this is primarily a low thinning with little or no impact on PCT development. The data from Joyce et al. (1998) in Table 1 reflects a first crown thinning.

Thinning intensity is the rate at which volume is removed, e.g. 10 m^3 ha^{-1} $year^{-1}$ (Rollinson 1988). Marginal Intensity represents the upper limit of volume that can be removed in a single intervention without causing a loss of cumulative volume production. Marginal intensity is defined as 70% of the YC × the thinning cycle (in years). Thinning control may therefore be based on inventory data using volume and/or basal area. While "stems ha^{-1}" is not recommended as a formal means of control, it does represent a useful guide, assuming the correct type of thinning has been carried out (Rollinson 1988).

A highly systematic use of inventory data to guide thinning control may however, detract from the forester's observation of PCT crown development requirements. As stated previously, broadleaves must maintain well-balanced, even crowns. This is particularly true for ash, which requires crowns continually free from competition and growing quickly from an early age to produce quality timber (Kerr and Evans 1993, Savill 2003, FRAXIGEN 2005). Applied at a practical management level, i.e. during the marking of the thinning, intensity control may therefore, be based to a large extent on the number of stems removed in order to free up PCT crowns. Apparently, only Short and Radford (2008) and Hein and Spiecker (2009) provide intensity guidelines based on selectively removing a specific number of trees which are in direct competition with any given PCT.

The principal silvicultural texts (Table 1) generally agree that ash thinning should be "early," "heavy" and "frequent". These are highly subjective terms which require further clarification with regard to timing, rate of removal, resultant effects on growth and schedule of subsequent interventions. Short and Radfords' (2008) guidelines on thinning intensity in Irish broadleaf plantations are highly practical in their application. However, the effects of the prescribed systems on stand growth and dynamics are as yet relatively unknown. Ongoing research into thinning intensity, the structural distribution of removals, the related impacts on PCT crown development, stem quality and volume increment is required to inform and update future management guidelines.

Knowledge of the dynamics of even-aged stands of ash is poor; for example, there is not yet any explanation for the belief that the window for a response to thinning is smaller for ash than for some other broadleaved species (Kerr and Cahalan 2004). Investigating the relationship between crown development and stem volume increment could ultimately lead to a better understanding of the stand dynamics of ash, although few experiments have explored the impact of thinning on this relationship (Dobrowolska et al. 2011).

Some of the most comprehensive modelling experiments on the relationship between crown characteristics and stem development in *F. excelsior* were carried out by Ottorini et al. (1996). Based on the coniferous crown modelling work of Mitchell (1975) and Ottorini (1991), a wide range of crown attributes were recorded for dominant and co-dominant sample trees including: crown height, crown projection area (CPA), "competitive status", foliar volume and foliar biomass. Competitive status is measured by ratio of crown length to total height of the tree (Le Goff and Ottorini 1996). Crown height was positively correlated with foliar volume, which in turn was positively correlated with stem volume increment. Competitive status was positively correlated with stem volume increment (and to a lesser extent tree height). As a key determinant of PCT volume increment, competitive status provides a useful management tool, which is easily observed/measured, described and monitored. According to Table 1 for example, the competitive status of an ash PCT should be maintained at ≥0.33.

Thinning of oak

Next to ash, oak (*Quercus robur* Liebl. and *Q. petraea* Matt.) are collectively the second most widely planted species within the Irish afforestation programme (DAFM 2011). Being slower growing than ash, oak generally requires a much later first thinning intervention (Edwards and Christie 1981, Rollinson 1988), often around 25 years of age for typical yield classes. Top height at first intervention would still be around 10 m at this stage. Traditionally, thinning interventions in oak aim to provide frequent, relatively low impact inputs that avoid sudden structural changes within the stand (Kerr and Evans 1993) on thinning cycles of 5–10 years (dependent on YC).

In contrast to the traditional "gradualist" approach outlined above, some continental systems favour a "dynamic" approach to early thinning in oak. Everard (1985) states that:

> Nothing more than thinning highlights the differences between classical and progressive silviculture. The classical approach involves a late start to thinning, and a very gradual opening of the stand from below. Denmark can be regarded as leading in progressive thinning, and here broadleaved crops are thinned early, often and in the crowns.

Table 1: *Main factors that affect the timing and intensity of first thinning in ash.*

Publication	Trigger for first thin				No of PCTs selected	Intensity control of thinning			Cycle
	Top height (m)	Basal area[a] ($m^2 ha^{-1}$)	Age (yr)	Other		Stems removed	Basal area[b] ($m^2 ha^{-1}$)	Target stocking (stems ha^{-1})	
Edwards and Christie 1981[c]	11.3	18	15				9	1,121	5 yrs
Evans 1984	8-10	20-30		Live crown 50% stem height	350				5-7 yrs
Forestry Commission 1955	7.6-9.1							2,717	3-4 yrs
FRAXIGEN 2005	6-7[e]			Live crown >33% tree height					
Hart 1991	10			Live crown 50% stem height	270-540				
Horgan et al. 2003	10				350-400				
Joyce et al. 1998	10				1,000[d]			1,000	+3 m TH[f]
Kerr and Evans 1993	8-10	20-30		Live crown >33% tree height	350				
Rollinson 1988[c]	12	18	15						
Short and Radford 2008	>8				300	Racks 1 line in 7, 2-3 competitors per PCT		≈ 1,300	+4 m TH

[a] Threshold basal area; [b] Target basal area; [c] Yield Class 10; [d] All remaining stems treated as PCTs prior to selection of 150 PCTs at Top Height 15 m;
[e] Includes pre-commercial thinning of naturally regenerated stands with potentially high initial stocking; [f] TH = top height

Sevrin (1997) outlines two French approaches that illustrate the change in classical and progressive silviculture. A traditional approach whereby first thinning begins when trees reach 8–15 m top height, depending on intensity of previous management, and removes one or two badly formed stems and impeding trees per high quality stem, the subsequent thinning occurring 12–15 years later. A "dynamic" system is also outlined where first thinning begins at 8–12 m top height and all crown competitors of 70 selected high quality stems ha^{-1} are removed, the subsequent thinning occurring 6–8 years later. Modelled on a French system, Joyce et al. (1998) promote earlier "tending" operations in Irish plantation oak (from a top height of 6 m) whereby wolves and defective stems are removed in one or two interventions before systematic crown thinning commences at a top height of about 14 m. This reflects traditional oak silviculture in the north of France whereby successive/frequent early cleaning or tending operations remove unwanted poor quality trees, albeit from stands derived from natural regeneration and potentially with initial stockings in the tens of thousands. Formal crown thinning in traditional oak silviculture in France is initiated much later in the rotation (age 30–50 years) than in British systems, although tending does blend somewhat into the crown thinning stage (Evans 1982). The dynamic approach aims to take advantage of distinct phases early in the rotation, i.e. close spacing in youth to assist natural pruning and maximise clean bole length, but also facilitating "early crown thinning to optimise the potential of the juvenile growth phase for crown development" (Joyce et al. 1998). A similar phased approach with an early natural pruning followed by a second PCT crown release phase has also been promoted within oak silviculture in Germany. In this system it is accepted that the promotion of crown development decelerates natural pruning, therefore the development of the desired clear bole length is achieved in closed stand conditions in the early rotation, which is followed by selective crown thinning of PCTs (Spiecker 1991, Hein and Spiecker 2009), predicated on the finding that stem diameter is closely correlated with crown width.

Facilitating early and ongoing crown development in order to maximise stem increment production has become an increasingly popular concept. Hemery et al. (2005) demonstrate the linear (r^2>0.8) relationship between crown and stem diameter in 11 common UK broadleaves. If this ratio is maintained, through thinning, PCT crowns (and therefore stems) may accrue their maximum increment. Modelling optimum crown space at a given DBH can be used to indicate desired basal area or stocking (Hemery et al. 2005). In north-western Spain, stand density tables were produced for pedunculate oak (*Q. robur*) that aim to provide dynamic thinning models based on desired stand attributes of height, diameter and volume (Barrio Anta and Álvarez González 2005). Recent Swedish research promotes crown / stem ratio modelling in pedunculate oak as the basis for silvicultural management and suggests that early, heavy thinning combined with high pruning, initiated early and repeated at regular intervals, may maintain timber quality, accelerate achievement of target diameter and therefore help shorten rotation length (Attocchi 2015).

A system which stimulates vigorous crown development of selected trees, in order to achieve maximum radial stem increment (Jobling and Pearce 1977) is commonly referred to as "free growth." It has also been called "free-thinning" and is associated with "crown release" thinning. In contrast to the aforementioned, relatively regular and gradual oak silvicultural systems, the free growth system can be viewed as an intense form of selective crown thinning in which a limited number of the best dominants are freed from crown competition from the first thinning onwards by felling any tree that touches the crown of a selected tree. The Forestry Commission (1955) suggested that about 100 dominants per acre (250 ha^{-1}) are selected. Research in Britain on free growth of broadleaves did not begin until 1950. Several hundred hedgerow and parkland oak were examined in the first study and showed that these free-grown trees had markedly greater radial stem increment than trees in forest stands (Hummel 1951), leading to the suggestion that a relatively small number of well-formed trees, selected early in the rotation and pruned to encourage clean boles, could result in a complete stocking of valuable trees at maturity. After a free-growth treatment was applied to a 19-year-old oak plantation (*Q. robur* and *Q. petraea*), stem volume and DBH increased compared with control and light crown thinning treatments (Kerr 1996), but pruning was required to ensure stem quality was maintained. It may be thought that the free-growth system is not suitable for oak, due to the requirement for pruning of epicormics and the additional expense of this action. Indeed, Kerr (1996) did wonder whether this was the reason that free-growth of oak was not common in Britain, and that it may be more applicable to cherry (*Prunus avium*), sycamore (*Acer pseudoplatanus*), ash (*Fraxinus excelsior*) and mixed stands of such species. However, Beinhofer (2010) modelled the free-growth system, with and without pruning, and compared it with conventional management of oak. Results showed that oak grown using the free-growth system and pruned provided a better financial return than conventionally grown oak or unpruned free-grown oak. Whether pruning was carried out or not, the free-growth system was still financially more attractive than the conventional method (Beinhofer 2010). Pruning of epicormics is one of the silvicultural operations recommended by Jobling and Pearce (1977) for free grown oak where the objective was to produce veneer-quality timber in a rotation of less than 100 years. They recommended that 60–80 well-formed dominant trees ha^{-1} be selected when mean height was >8 m and that they should be evenly spread through the stand. All trees whose crowns were within one quarter of the mean crown width of the chosen trees were then removed by thinning. Pruning of epicormics and side branches of the chosen trees, to an ultimate height of 6 m, had to be carried out.

The crowns of the chosen trees were subsequently maintained free from competition by successive thinnings carried out every 3–5 years. A similar system was described by Lemaire (2010). The French "sylviculture dynamique" system similarly aimed to produce high quality oak in a rotation of less than 100 years. In this system 70 stems ha^{-1} were selected before dominant tree height reached 16 m and stems that were competing in the canopy with them, as well as those <2 m distance from their canopy, were removed. Suppressed stems and those not directly competing with the selected stems remained to help prevent epicormics but pruning was also carried out on the selected stems as required.

All of the principal texts on oak silviculture concur that epicormic or side branching can be a major problem in the production of quality timber. Thinning practice should avoid exacerbating this problem (Horgan et al. 2003). While one proposed benefit of the dynamic system outlined above is increased diameter increment leading to more rapid achievement of target diameter and the shortening of rotations, a further benefit may be that healthy vigorous PCTs are less susceptible to the development of epicormic branching. Although first interventions in oak are perceived as being relatively late (in terms of age), if crown size is allowed to deteriorate through very late and light thinning then the resultant stress may also promote epicormic development (Joyce et al. 1998). The dynamic system seeks to minimise any growing stress through the development of healthy PCT crowns. Albeit dedicated crown thinning does not appear to commence until relatively long clear boles (Hein and Spiecker 2009) or tall (Joyce et al. 1998) top heights have been achieved. Everard's (1985) observations on French and Danish oak silvicultural systems state that epicormics are best controlled through early and heavy thinning. Somewhat conversely, the traditional gradualist approach discourages epicormic development through frequent light thinning and the minimisation of stand structural changes (Evans 1984). In the case of late thinnings, a drastic return to the desired stocking may also promote epicormics (Shapland 1966). Timely intervention is therefore critical.

North American research on mixed-oak stem quality (Sonderman and Rast 1988) points out that while heavier thinnings increased the crown class (relative crown proportions) of dominant trees and PCTs potentially facilitating shorter rotations, light frequent interventions (akin to the traditional UK systems) resulted in fewer and smaller side branches throughout the stand, albeit with much slower diameter increment. Further US research trials on oak thinning intensity suggested that trees with higher crown class scores (the more dominant trees) continued to have fewer epicormics than trees with lower crown class scores across a range of intensity treatments (Dimov et al. 2006). One note of caution however, is that external environmental factors may promote epicormic development, therefore making the assessment of the outcomes of silvicultural practice more difficult (Lockhart et al. 2006). While these US observations restate the pros and cons of early vs. late and/or heavy vs. light thinning, they also reinforce the benefits of developing and maintaining healthy and balanced PCTs (as opposed to a stand based management approach), which should be the central focus in broadleaf silviculture.

In view of the large body of information and experience available, the thinning of oak is perhaps more complex than most other broadleaved species. This being the case it may be prudent, particularly from the low starting base of Irish plantation silviculture, to observe the fundamental principle of maintaining well-balanced PCT crowns. If this requires earlier or heavier thinning than some systems dictate, then the pruning of epicormics is likely to be a necessary, complimentary operation.

Thinning of beech

Like oak, beech (*Fagus sylvatica* L.) has traditionally a relatively late first thinning intervention (Edwards and Christie 1981). However, particularly when derived from natural regeneration, beech can have very high initial stocking rates requiring pre-commercial tending interventions (Joyce et al. 1998, Skovsgaard et al. 2006). These may be selective in terms of taking out poorly formed individuals (Joyce et al. 1998), which are common in young beech stands. However, in very densely stocked stands such operations may be costly and some form of systematic (mechanical) thinning, in terms of taking out lines or racks may be more practical (Evans 1984, Skovsgaard et al. 2006). Short and Radford (2008) recommended no initial tending intervention for Irish beech plantations (irrespective of initial stocking). For pure beech at a stocking of 6,600 stems ha^{-1} they recommended a combination of systematic and selection thinning commencing at a top height of 12–15 m. This contrasts with Joyce et al. (1998), who recommended an initial stocking reduction from 6,600 to 2,500–3,000 stems ha^{-1} at a top height of 5–8 m. This is a low thinning and they reached a similar position to Short and Radford (2008) that crown thinning should commence at 12–15 m. Given that many beech plantations in Ireland, up until 2011, were established with a conifer nurse; the removal of this nurse is likely to form the basis of the first thinning. Short and Radford (2008) make provision for this in a two phase tending/thinning prescription. However, as beech in Ireland is now (since 2011) planted pure at only 3,300 stems ha^{-1}, any new guideline related to this configuration is likely to retain the maximum stocking in an effort to achieve a desired clear bole length prior to a first crown thinning. (This general situation also applies to oak plantations in Ireland pre/post 2011.)

The general approach for the early treatment of beech is to retain high stocking until PCTs achieve a clear bole length of 6–8 m (Brumme and Khanna 2009), followed by heavy crown thinning to encourage rapid diameter increment (Kerr and Evans 1993), as fast-grown beech is preferred for nearly all end-uses over slow-grown (Evans 1982). Boncina et al. (2007) demonstrated that selective crown thinning in beech may result in dominant tree (PCT) increment 30–56% higher than that of the dominant trees in unthinned stands. Other studies in European beech stands have shown that, on favourable sites, accelerated increment can be related to increased thinning intensity (Pretzsch 2005, Štefančík 2013). It may therefore be that traditional yield models have underestimated the potential diameter increment in European beech (Hallenbarter et al. 2005) and more current dynamic growth models need to be developed (Álvarez-González et al. 2010).

It has also been shown that beech stands can cope better with climatic (moisture and temperature) fluctuations when intra-species competition is reduced, i.e. through thinning, resulting in positive growth outcomes for the remaining trees (Cescatti and Piutti 1998, Van der Maaten 2013).

Beech is the most shade tolerant broadleaf used in Irish forestry (Hill et al. 1999) and with high crown plasticity (Schröter et al. 2012), unlike ash for example, can respond well to thinning even after a period of neglect (Kerr and Evans 1993). However, Štefančík (2015) pointed out that delayed (and less intensive thinning) can result in lower quantitative production.

Most authors agree that beech thinning should focus on a desired clear bole length. This change of focus, somewhat away from the maintenance of PCT crown proportions, is facilitated by beech's shade tolerance and related crown plasticity. Brumme and Khanna (2009) leave first thinning relatively late – 40 to 60 years – to achieve the desired clear bole length. The reason for this disparity with other guidelines is unclear although it may be due to less vigorous growing conditions and they do specify a slightly longer bole. Most authors however, agree that once the target bole length is achieved, subsequent thinning should be moderately heavy and frequent in order to maximise PCT crown development and therefore volume increment.

Thinning of sycamore

Standard UK guidelines include the same early thinning criteria, top height, threshold basal area, etc., for sycamore (*Acer pseudoplatanus* L.) as for ash (Edwards and Christie 1981, Rollinson 1988). More applied guidelines relating to Irish plantation silviculture also make the same prescriptions for the initial thinning of the two species (Short and Radford 2008). Hein and Spiecker (2009) treat the two species growth habits and silvicultural requirements as very similar in their allometric models linking target diameter, rotation length and stocking.

Certainly the need for early and heavy thinning to maintain vigorous crowns in sycamore has been well documented in Irish and UK forestry (Bolton 1949, Hiley 1955, Stevenson 1985, Stern 1989, Kerr and Evans 1993, Horgan et al. 2003). Evans (1984) promotes early and frequent interventions, particularly on fertile sites, and heavy crown thinning, to the point of free-growth in order to drive rapid diameter increment, on more sheltered sites. Horgan et al. (2003) concur with the recommendation for a first heavy

Table 2: *Main factors that affect the timing and intensity of first thinning in oak.*

Publication	Trigger for first thin				No of PCTs selected	Intensity control of thinning			Cycle
	Top height (m)	Basal area[a] (m^2 ha^{-1})	Age (yr)	Other		Stems removed	Basal area[b] (m^2 ha^{-1})	Target stocking (stems ha^{-1})	
Edwards and Christie 1981[c]	10.4	24	25				20	3,529[d]	5 yrs
Evans 1984	8-10	20-30			200				5-7 yrs
Forestry Commission 1955: 1st thinning	9-10.5			Work to a light grade. Eliminate wolf and whip trees.				2,700-3,460	5 yrs
Forestry Commission 1955: 2nd thinning				Work to a moderate grade. Eliminate whips.					5 yrs
Hochbichler 1993	13-15		30	Start of selective thinning	60-70	1 – 2 competitors per selected stem			
Horgan et al. 2003					300-400				
Joyce et al. 1998: 1st tending	6-7							3,600[d]	
Joyce et al. 1998: 2nd tending	10-11							1,900-2,100	
Joyce et al. 1998: crown thinning	13-15			Target clear bole length achieved.	100			1,000-1,300	+ 1.5-2 m TH[e]
Kerr and Evans 1993	8-10	20-30			200				

Publication	Trigger for first thin				No of PCTs selected	Intensity control of thinning			Cycle
	Top height (m)	Basal area[a] ($m^2\,ha^{-1}$)	Age (yr)	Other		Stems removed	Basal area[b] ($m^2\,ha^{-1}$)	Target stocking (stems ha^{-1})	
Lemaire 2010	9-12			Prune selected trees and halo thin the following year.	70				
Rollinson 1988[c]	12	26	28						
Sevrin 1997	8-15			In favour of the best trees, gradually remove 1 or 2 trees that impede or have poor form or a defect.	Not yet selected				12-15 yrs
Sevrin 1997	8-12			Remove all trees that interfere with the PCT crowns.	70				6-8 yrs
Short and Radford 2008	10-12				340	Racks 1 line in 7, 1-2 competitors per PCT		≈4900[d]	

[a] Threshold basal area; [b] Target basal area; [c] Yield Class 6; [d] Initial stocking >6,000 stems ha^{-1}; [e] TH = top height

Table 3: *Main factors that affect the timing and intensity of first thinning of beech.*

Publication	Trigger for first thin				No of PCTs selected	Intensity control of thinning			Cycle
	Top height (m)	Basal area[a] ($m^2 ha^{-1}$)	Age (yr)	Other		Stems removed	Basal area[b] ($m^2 ha^{-1}$)	Target stocking (stems ha^{-1})	
Edwards and Christie 1981[c]	11.4	23	30				20	3,946[d]	5 yrs
Evans 1984	8-10	20-30			250				5-7 yrs
Forestry Commission 1955	9			If badly shaped trees are numerous remove the worst of these and favour good trees. In more normal crops employ a light grade thinning				3,459	
Horgan et al. 2003				Clean bole min 6 m	300-400				
Joyce et al. 1998 – 1st tending	5-8							2,500-3,000	
Joyce et al. 1998 – crown thinning	12-15			Target clear bole length achieved	150			1,500	+ 2-3 m TH[e]
Kerr and Evans 1993	8-10	20-30		Clean bole min 7 m	250				
Rollinson 1988[c]	12	24	30						
Short and Radford 2008	10-12				340	Racks 1 line in 7, 1-2 competitors per PCT		≈ 4,900[d]	
Brumme and Khanna 2009	15		40 – 60	Clean bole 6 – 8 m	80-160				4-6 yrs

[a] Threshold basal area; [b] Target basal area; [c] Yield Class 6; [d] Initial stocking >6,000 stems ha^{-1}; [e] TH = top height

crown thinning followed by ongoing selection thinning aimed at the continual release of PCT crowns. They also recommend the retention of the middle and understorey (where possible) in order to control the development of epicormics in PCTs.

Perhaps the most comprehensive recent review on sycamore silviculture in Europe was carried out by Hein et al. (2009a), who questioned the widespread applicability of historical guidelines which are based on assertions and observations that have not been objectively tested. They highlight a lack of published research material on sycamore silviculture which takes into account modern management objectives, e.g. the production of high quality timber over short rotations. Traditional diameter increment predictions based on yield tables may be based on "average" crops that have been subjected to moderate, un-quantified thinnings and do not necessarily reflect modern thinning regimes. Hein et al. (2009a) outline the current requirement to improve stand economics and achieve merchantable stem dimensions and target diameter in the shortest possible rotation. In this scenario they reflect on the potential gains which may be made by heavier thinnings, up to a given threshold (Plauborg 2004), particularly during the vigorous early rotation phase (Nagel 1985) up to about 20–25 years. Various models which aim to maximise stem quality, and crown and diameter increment, are considered. Knowledge gaps are identified and the need for further research highlighted. In general terms however, early and heavy thinning in sycamore, in support of positive economics, would appear to remain the focus of most authors, from the reflections of Lord Bolton (1949), who favoured increasingly early interventions in his high quality sycamore stands, through to more contemporary literature. Any apparent change of focus relates more to modelling growth and treatment outcomes as opposed to silvicultural practice by experience and observation. Both approaches may inform practical management guidelines.

Thinning of cherry

Little debate surrounds the thinning of cherry where "early, heavy and frequent" is the common recommendation (Pryor 1985, Kerr and Evans 1993, Joyce et al. 1998, Horgan et al. 2003). Cherry is highly sensitive to crown competition, particularly after its fast growing phase up to about 20 years (Joyce et al. 1998), and under-thinning is likely to result in loss of increment and possibly crown dieback (Pryor 1985). As cherry is best grown as a minor component in mixed broadleaved stands (Evans 1984, Kerr and Evans 1993, Loewe et al. 2013), PCTs cannot be allowed to lose their place in the canopy as they are unlikely to recover it (Stojecová and Kupka 2009). Crown thinning should commence when around 8 m top height is attained (Horgan et al. 2003) and should focus on removing PCT competitors to allow adequate growing space throughout the thinning cycle (Kerr and Evans 1993). Subsequent thinnings should be frequent and heavy, to the point of free-growth (Horgan et al. 2003), in order to achieve large diameter timber in the shortest possible rotation (Kerr and

Table 4: *Main factors that affect the timing and intensity of first thinning in sycamore.*

Publication	Trigger for first thin				No of PCTs selected	Intensity control of thinning			Cycle
	Top height (m)	Basal area[a] ($m^2 ha^{-1}$)	Age (yr)	Other		Stems removed	Basal area[b] ($m^2 ha^{-1}$)	Target stocking (stems ha^{-1})	
Edwards and Christie 1981[c]	11.3	18	15				9	1,121	5 yrs
Evans 1984	8-10[c]	20-30[c]		Maintain deep crown	350				≤6 yrs
Forestry Commission 1955				Similar to that of ash but more shade tolerant and can carry more stems ha^{-1}					
Horgan et al. 2003	12			Live crown >33% tree height	200-300				+ 2-3 m TH
Joyce et al. 1998	12-14				150			1,000	+ 2-3 m TH[d]
Kerr and Evans 1993	8-10	20-30			350				
Rollinson 1988[a]	12	18	15						
Short and Radford 2008	>8				300	Racks 1 line in 7, 2-3 competitors per PCT		≈ 1,300	+4 m TH[d]

[a] Threshold basal area; [b] Target basal area; [c] Yield Class 10; [d] TH = top height

Evans 1993). Joyce et al. (1998) recommend retaining half or even two thirds of the height of the tree in live crown. Such open growth will clearly entail lower stocking densities at a given top height compared to other commercial broadleaved species (Hein and Spiecker 2009) and PCTs will require judicious pruning (Pryor 1985, Pakenham 2005). An allometric equation is provided in Pryor (1988) relating stem and crown diameters (Equation 1).

$$\text{Crown diameter (m)} = 1.19 + 0.158 \times \text{DBH (cm)} \quad (R^2 = 0.88) \qquad (1)$$

There is a high correlation between the two, suggesting that if a tree's crown is impeded then its stem diameter will be correspondingly restricted. To obtain good stem diameter growth rates, Pryor (1988) suggests that stocking should never be allowed to rise above the values corresponding to 100% canopy closure in Table 5. Extended thinning cycles will require thinning to a much lower canopy closure percentage to prevent 100% closure being attained prior to the next thinning.

Duyck (1997) provides a model for the silviculture of cherry in the Normandy region of France (Table 6). Comparing the mean diameter of the main stand after thinning and the number of stems remaining with the data in Table 5, the stocking rate of Duyck (1997) closely resembles that of Pryor (1988) with 60% canopy closure, suggesting that 60% is a target canopy closure for thinning operations.

Thinning of alder

There is little literature regarding the thinning of alder (*Alnus glutinosa* or *A. cordata*). Nisbet (1893) says about alder:

> Its treatment in pure forest is as a rule rather as coppice than as high timber forest, after its growth has once been begun; the original formation of crops usually takes place by means of planting rather than by either natural or artificial sowing (Nisbet 1893, p. 228).

He goes on to describe coppicing of alder and its management but at no point discusses the management of alder as a high forest.

Recent proposals for the thinning of alder (e.g. Poulain 1991, Vaast and Billac 1996, Claessens 2005) suggest intensive and especially early thinning regimes beginning at age 10–15 years. Two methods are commonly used:

- stand thinning – a homogenous thinning of the whole stand, favouring more or less equally all the trees remaining after thinning;
- crop tree thinning – a crown thinning that concentrates on removing competitors of a small number of selected trees of high potential quality that will form the final stand, creating space around the crown of the future crop trees.

Savill (2013) recommends crop thinning. It should be started early and must be

Table 5: *Estimated number of cherry stems ha^{-1} for a range of mean stand diameters and degrees (percentage) of canopy closure (Pryor 1988).*

Mean stem diameter	Mean crown diameter	Numbers per ha. at % canopy closure of:				
(cm)	(m)	100%	90%	80%	70%	60%
10	2.8	1,624	1,462	1,299	1,137	974
15	3.6	982	884	786	687	589
20	4.3	689	620	551	482	413
25	5.1	490	441	392	343	294
30	5.9	366	329	293	256	220
35	6.7	284	256	227	199	170
40	7.5	226	203	181	158	136
45	8.3	185	167	148	130	111
50	9.1	154	139	123	108	92

Table 6: *Guide to silviculture of cherry in the Normandy region of France (Duyck 1997).*

Age	Main stand before thinning					Thinning				Main stand after thinning				
	No. stems ha^{-1}	Dominant height (m)	Mean diameter (cm)	Surface area ($m^2 ha^{-1}$)	Total volume ($m^3 ha^{-1}$)	No. stems	Mean diameter (cm)	Surface area ($m^2 ha^{-1}$)	Total volume ($m^3 ha^{-1}$)	No. stems	Dominant height (m)	Mean diameter (cm)	Surface area ($m^2 ha^{-1}$)	Total volume ($m^3 ha^{-1}$)
15	690	9.9	13.6	10.01	40	90	10.48	0.78	3	600	9.9	14.0	9.24	37
20	600	12.5	18.6	16.24	85	205	17.44	4.90	25	395	12.5	19.1	11.34	60
25	395	15.1	23.7	17.44	113	114	21.86	4.27	27	281	15.1	24.4	13.17	86
31	281	17.9	29.9	19.71	155	78	27.39	4.58	36	203	17.9	30.8	15.13	120
37	203	20.1	36.2	20.95	188	46	33.61	4.07	36	157	20.1	36.9	16.87	152
44	157	22.0	43.2	23.10	230	35	40.01	4.36	43	123	22.0	44.1	18.74	187
52	123	23.3	51.3	25.38	270	26	47.37	4.65	48	96	23.3	52.3	20.74	221
60	96	24.1	59.6	26.90	297	19	54.33	4.31	47	78	24.1	60.8	22.58	250
69	78	24.5	69.1	29.15	328						24.5			

heavy and frequent around the selected final crop trees to achieve marketable timber before heart rot sets in. He goes on to state that alder does not respond to delayed thinning. Claessens (2004) provides more detail of a crop thinning system, providing the minimum distance between future crop trees and their nearest neighbours as a function of their height and DBH (see Table 7).

Rytter and Werner (2007) report results of a replicated black alder (*A. glutinosa*) thinning trial in Sweden. The stand used was derived from natural regeneration with a stocking density of 20,000 stems ha^{-1}. Table 8 illustrates a standard tending/thinning regime for such a stand. Three replicates of two thinning treatments and a control were investigated. The two thinning treatments reduced stocking density to 1,433 and 1,067 stems ha^{-1} for the standard and strong thinning treatments, respectively. Both thinning treatments resulted in a significant increase in DBH after three years compared to the control treatment and both the thinning treatments were similar to each other. The mean crown diameter of the stems in the thinned treatments was significantly greater than those in the control treatment one year after thinning, implying that the crowns of the stems in the thinned treatments had expanded to utilise the additional space available to them.

Alder constitutes 9% of the Irish broadleaf forest estate (Government of Ireland 2013). Neither Horgan et al. (2003) nor Joyce et al. (1998) provide any advice on the thinning of alder in an Irish context except to say that it doesn't respond to delayed thinning. Short and Radford (2008) provide some recommendations, suggesting that more than 350 potential crop trees ha^{-1} should be selected when the stand top height is 8 m and then at least two competitors per PCT should be removed. The next thinning is recommended to take place when top height is 12–15 m and 2–3 competitors per PCT are thinned. Short and Radford (2008) provide no advice for later thinnings.

Table 7: *Minimum approximate distance between a future alder crop tree and its nearest neighbour (trunk to trunk) should be a function of total height and DBH of the future crop tree -all values in metres (recalculated from Claessens (2004)).*

Total height of the future crop tree (m)	**Minimum distance between future crop tree and its nearest neighbour (m)**
9	30 × DBH
12	27 × DBH
15	24 × DBH
18	21 × DBH

Note: Actual formula uses circumference at 1.3 m height. The above approximates the cited formula by substituting circumference with 3 × DBH (approximating π × DBH).

Table 8: *Recommended number of remaining* Alnus glutinosa *stems after thinning (Rytter and Werner 1998).*

Tree height (m)	**Stems remaining after thinning**
2–3	2,000–2,500
6–7	1,200–1,400

Thinning of birch

The interest in silver and downy birch (*Betula pendula* Roth. and *B. pubescens* Ehrh., respectively) as commercial broadleaf species has only recently begun to develop in Ireland (O'Dowd 2004, Renou et al. 2007). This same interest gained momentum some years previously in the UK, during the early nineties (Cameron 1996), and surprisingly, 50 years prior to that birch was still considered a weed species in Scandinavian forestry (Lorrain-Smith and Worrell 1992). Following an extensive improvement programme launched in Finland in 1960 (O'Dowd 2004), birch timber is now a significant component of Northern and Eastern European commercial forestry output (Hynynen et al. 2009, Liepiņš et al. 2011). This being the case, much of the literature on the silvicultural management of birch originates in Scandinavia and may therefore be difficult to transfer to Irish plantation forestry conditions. For example, many Scandinavian stands are derived from highly stocked (mixed species) natural regeneration origin (Hynynen et al. 2009), requiring timely (before reaching 5–7 m height) pre-commercial thinning interventions in order to maintain the crown proportions and vigour of the dominant trees (Fällman et al. 2003, Rytter and Werner 2007). In Finland however, pure birch plantations generally require no pre-commercial thinning (Hynynen and Niemistö 2009). Certain fundamental silvicultural characteristics of the species may be applied to birch stands in general. "Birch requires ample head room, and when once the chief un-wanted classes (whips and wolves) have been eliminated the grade of thinning adopted should be moderate to heavy" (Forestry Commission 1955).

To further qualify the above statement; birch is a strong light demander and requires heavy thinning to ensure minimal competition from surrounding trees (Cameron 1996). Birch PCTs only maintain their vigour and diameter increment when growing as dominant trees at relatively wide spacing with a low degree of competition. First commercial thinning should be carried out before the crown ratio of the dominant trees fall below 50% (Horgan et al. 2003, Hynynen et al. 2009, Hynynen and Niemistö 2009). If, through neglect, crown proportions are allowed to fall much below this figure, birch stands rarely recover (Cameron 1996). The "two-phase," which is an early close spacing followed by crown release, a concept described by Hein and Spiecker (2009) for oak, ash, sycamore and cherry is not appropriate for birch (Hynynen et al. 2009). The birch requires early and heavy thinning (Rytter and Werner 2007), until full and permanent crown release is achieved in order to grow large dimensioned, high value timber. Various authors put the top height threshold for first thinning in birch between 10–15 m however, maintaining the appropriate live crown ration should take precedent over top height as a first thin trigger, and it is notable that UK and Irish guidelines (Worrell 1999 and Horgan et al. 2003) put the top height threshold closer to 10 m.

In Scandinavia commercial thinning is carried out when dominant height is between 12–15 m with stocking reduced from 1,600–3,000 stems ha^{-1} to 600–700 stems ha^{-1} (Raulo 1987, Mielikäinen et al. 2007). In Latvian birch silviculture the pre-commercial thinning phase in natural stands begins at 3–6 m stand height, leaving 1,500–2,000 stems ha^{-1} (Zālītis and Zālītis, 2007). Commercial thinnings are carried out twice during the rotation: the first at an average height of 14–15 m, leaving about 1,200 stems ha^{-1}, the second at a height of 21–24 m, leaving 500–600 stems ha^{-1} (Liepiņš et al. 2011). Thinning from below is the conventional silvicultural method practiced in Latvia. Birch rotations in northern Europe are generally between 40–60 years depending on site productivity (Mielikäinen et al. 2007, Hynynen et al. 2009).

Based on trials in Silver birch in southwest Germany, Hein et al. (2009b) point out that natural pruning is poor as even dead lower branches are slow to shed. In keeping with the above, they recommend an early intensive release of PCTs combined with pruning to 5 m stem height in order to minimise wood defects. Hein et al. (2009b) also advise growing to target diameter no greater than 45–50 cm as birch diameter increment drops off rapidly after about 25 years, even with continued PCT crown release. Furthermore rotation lengths in excess of 50–55 years (95-120 final crop trees ha^{-1}) are likely to result in discolouration of the timber.

Worrell (1999) provides some useful practical guidelines on birch thinning in UK forestry conditions (based partly on Scandinavian silvicultural practice):

- respacing of naturally regenerated stands, ideally when 1.5–2 m tall and before 6 m, to about 2 m spacing or 2,500–3,000 stems ha^{-1}. Planted material should also be at this initial stocking.
- in pre-commercial thinning remove suppressed and poorly formed trees – misshapen stems and small crowns; favour silver birch over downy; favour seedlings over coppice shoots, but where coppice shoots are retained they should be singled to one or two stems per stool; retain the best co-dominants and dominants of exceptional form.
- two broad thinning options: “Heavy” commercial thinning – 2 to 3 thinnings over a 45–60 year rotation; *or*, “frequent” commercial thinning – cycles of 5–10 years.
- thin from a top height of 10 m in “frequent” thinning to 1,400–1,600 stems ha^{-1}; 5 to 7-year cycles early in the rotation and 8 to10-year cycles later in the rotation.

Worrell (1999) also suggests that the heavy thinning interventions, as detailed in Table 10, are appropriate to Britain.

Worrell (1999) suggests slightly shorter rotation lengths for British birch than for birch in Scandinavia – 35 to 40 years on better sites with adequate thinning, to 65 years

Table 9: *Main factors that affect the timing and intensity of first thinning in birch.*

Publication	Trigger for first thin				No of PCTs selected	Intensity control of thinning			Cycle
	Top height (m)	Basal area[a] ($m^2\,ha^{-1}$)	Age (yr)	Other		Stems removed	Basal area[b] ($m^2\,ha^{-1}$)	Target stocking (stems ha^{-1})	
Edwards and Christie 1981[c]	11.3	18	15				9	1,121	5
Worrell 1999: frequent thin	10			Live crown 50% tree height		≈ 1,000		≈ 1,500	5–7
Worrell 1999: 2 thin total	11 – 14		16+	Live crown 50% tree height		≈ 1,600		≈ 900	c. 13
Worrell 1999: 3 thin total	10 – 12		15+	Live crown 50% tree height		≈ 1,250		≈ 1,250	c. 10
Horgan et al. 2003	10			Live crown 50% tree height	700			1,500	
Raulo 1987	12 – 14					≈ 1,000–2,000		700–900	
Rollinson 1988[c]	12	18	15						

[a] Threshold basal area; [b] Target basal area; [c] Yield Class 10.

on poorer sites with lighter thinning. Average DBH at felling should be 25–35 cm, which assuming YC 10 was attained in well managed Irish birch stands, as suggested by Nieuwenhuis and Barrett (2002) for Irish-grown downy birch, could mean rotations as short as 30–35 years (Edwards and Christie 1981). It is encouraging that as improved birch material becomes available for use in Irish forestry, outline thinning prescriptions are already well advanced.

Thinning intensity trials and residual stand growth responses

One of the most prominent studies to quantify the effects of thinning intensity on the residual (post-thinning) broadleaf stand was carried out by Juodvalkis et al. (2005). They published the results of thinning experiments of six species in Lithuania, covering five broadleaves: pedunculate oak, silver and downy birch, aspen (*Populus tremula* L.) and common ash. The study was conducted over a 35-year period on 256 permanent sample plots in pure or nearly pure even-aged natural stands of high YC that were 10–60 years old when the study commenced. European studies on common ash show average YCs of 4–6 with a maximum of about 10 (FRAXIGEN 2005). Based on volume removed, low thinning intensity included 10, 15 and 20% volume removed; moderate intensity 25, 30 and 35%; and high intensity 40, 45 and 50%. No-thin controls were also included. Standard single tree and stand inventory data were recorded as height, DBH, volume, stocking, etc. "Crown surface area was estimated by measuring crown diameter in 8 different directions" (Juodvalkis et al. 2005).

The results (for all species) showed that:

Table 10: *Heavy thinning regimes for silver birch on a 45- to 60-year rotation (Worrell 1999).*

	2 thinnings	3 thinnings
First thinning		
Top height (m)	11 – 14	10 – 12
Age (yr)	16 – 28	15 – 25
Thinning volume (m^3 ha^{-1})	30 – 40	20 – 30
Stocking after thinning (ha^{-1})	800 – 1,000	1,200 – 1,300
Second thinning		
Top height (m)	18 – 20	15 – 16
Age (yr)	29 – 48	24 – 40
Thinning volume (m^3 ha^{-1})	40 – 50	35 – 40
Stocking after thinning (ha^{-1})	400 – 500	800
Third thinning		
Top height (m)	-	20 – 21
Age (yr)	-	34 – 60
Thinning volume (m^3 ha^{-1})	-	60 – 70
Stocking after thinning (ha^{-1})	-	400 – 500

Note: the decision on when to thin should be based on the *height* of the crop, rather than age. Age is included in this table for general planning purposes.

- residual trees occupied available space and enhanced their crown increment, and faster expansion of crowns was recorded in stands thinned to a larger degree;
- in older stands crown increment was lower than in younger stands;
- tree crowns started to react one year after thinning and reached maximum growth after 2–3 years, though different species reacted at different growth rates;
- the strongest reaction was in aspen and birch, crowns of which expanded up to three times faster than those grown in unthinned stands. Ash and oak more than doubled their crown surface area increment;
- after 3–4 years, rates of crown expansion started to decrease. However, due to the extensive crown growth of all four broadleaved species, total crown area in thinned stands became greater or equal to that in unthinned controls after 4–7 years;
- thinning promotes DBH increment, especially in younger stands, and the rate of increase in DBH is positively correlated with thinning intensity. This was true for all four broadleaf species, showing an increase already one year after thinning and reaching a maximum 2–3 years later;
- in general, DBH increment following thinning was greater in younger stands and heavier thinnings. However, there was an intensity threshold beyond which the increase of DBH increment was not further enhanced –this is defined as minimal stocking. Thus, in 10–20 year-old stands, minimal stocking comprised 30–40% canopy coverage and in 50–60 year-old stands 50–60%. In terms of basal area for broadleaves, this roughly corresponded to 3.5–8 $m^2 ha^{-1}$ at a mean height of 7–12 m, and 14–20 m^2 ha^{-1} at a height of 20–24 m;
- overall, stand volume increment was only maximised in light or moderate intensity thinnings, varying between 15–25% of volume even in the youngest stands. The thinning effect on volume increment was largest in 10 to 20-year-old stands and declined sharply in older stands and in 50 to 60 year-old stands further increase in volume was negligible (Juodvalkis et al. 2005).

The Juodvalkis et al. (2005) study covered a wide range of age classes, in naturally derived stands, in northern central Europe, therefore the practical applications for plantation silviculture in different geographic areas may be somewhat limited. However, the trends illustrated by the study may be able to inform broader silvicultural practice. The positive impact of thinning in relation to PCT growth response is clear, specifically the correlation between crown development and stem volume increment. The higher relative gains in early thinning also provides a general lesson in broadleaved silviculture. Juodvalkis et al. (2005) also indicate the importance of maintaining relatively short thinning cycles. Their findings on the positive growth implications of higher thinning intensities broadly concur with the other authors in this review and the concept of "minimal stocking" is one which can inform other studies in different geographical areas with different environmental and stand conditions.

Starting in 2005, Çicek et al. (2013) carried out a thinning intensity trial on narrow-leaved ash (*F. angustifolia* Vhal.) in north western Turkey. Two thinning treatments were applied in two separate experiments. The first on a 36-year-old plantation established at 1,666 stems ha^{-1}, the second on a 22-year-old plantation established at 730 stems ha^{-1}. Intensity regimes in the respective sites were controlled by basal area: 0% removal as controls; 19% and 22% removal, respectively as moderate intensity thinnings; and 28% and 39% removal, respectively as heavy thinnings. Standard measurements over a 6-year period included: DBH, height and basal area. While this trial involved a different species from common ash, and it was carried out in somewhat different environmental and silvicultural conditions than those found/employed in northwestern Europe, the treatments and results are nonetheless interesting and broadly concur with the previously reported findings with regard to the impact of thinning on diameter increment. Both experiments showed that thinning significantly increased residual diameter increment, in comparison to the controls, and the rate of increase in diameter increment was positively correlated with thinning intensity. Thinning intensity did not significantly affect height increment. Stand basal area and stand volume had not recovered to the levels of the control after six growing seasons. Volume increments were higher in the second site, with a heavier thinning on a younger crop than in the first site. Çicek et al. (2013) concluded with recommendations for ash thinning including common ash, which supports the view that the selection of PCTs should occur early in the rotation. Crown thinning should favour these trees, with "heavier" thinning early in the rotation to keep PCTs entirely free of competition.

The COFORD-funded Teagasc/UCD Broadleaf Silviculture Research and Development (B-SilvRD) programme included a thinning intensity trial which explored the effects of conventional rack and selective first thinning practice, as recommended by Short and Radford (2008), on PCT development in plantation ash over three growing seasons (Teagasc 2015). The B-SilvRD trial applied this general rack and selective prescription in two separate plots – one involving the removal two competitors per PCT and another with the removal of three competitors. The trial assessed any relative growth advantage for PCTs over the remaining stand matrix. It also aimed to discern any significant difference between 2- and 3-tree selection, with a particular emphasis on DBH and BA increment (Hawe 2014).

Given that individual PCTs subjected to a rack with 2- to 3-tree selective thinning are afforded varying levels of crown space, particularly where adjacent lines, additional diseased trees, etc. are removed, the actual crown space afforded to individual PCTs in the B-SilvRD trial was assessed both by recording their actual number of immediate neighbours remaining post-thinning and by recording whether a PCT was adjacent to a rack. PCTs in each intensity treatment showed significant DBH increment gains over the remaining stand matrix ($p \leq 0.0001$ at each measurement period). There was no significant difference in DBH and BA increment on the PCTs between the two thinning intensity treatments. The number of neighbours remaining was negatively correlated with PCT diameter increment. However, overall PCT increment gains in relation to the remaining number of neighbours was only significant at the first measurement period ($p = 0.0462$). Only those PCTs with the greatest individual canopy space continued to show significant growth increments throughout the trial, i.e. the number of neighbours effect combined with a rackside situation showed significant DBH increment gains at each measurement period ($p = 0.0124$, $p = 0.0069$ and $p = 0.0061$).

The three trials described above (viz. Juodvalkis et al. (2005), Çicek et al. (2013) and the B-SilvRD trial (Hawe 2014) cover quite different geographic areas and stand configurations. However, a common theme is the maximisation of PCT growth increment through increased thinning intensity, to the point of minimal stocking (Juodvalkis et al. 2005). Clearly the maximisation of PCT growth increment cannot be at the expense of timber quality and, for some species, is likely to require a complementary pruning treatment(s). This concept may however, be explored through further trials and is potentially of great interest to the silviculture of the most widely planted commercial broadleaf species in Ireland.

Modelling PCT growth responses to provide management guidelines

Gaining a better understanding of stand growth responses to thinning may ultimately lead to more effective management prescriptions to facilitate desired production objectives, i.e. target log length/diameter within a given timeframe.

Hein and Spiecker (2009) described the allometric modelling of crown width for common ash, sycamore and wild cherry, which in turn provides some practical silvicultural management guidelines for certain production objectives. The models are based primarily on crown width (not defined), which is correlated with DBH, and consider production objectives such as clear bole length, target diameter and rotation length. Having demonstrated the strong link between crown width and DBH ($r^2 = 0.88$), the models predict the rotation lengths required to produce various target harvesting diameters, across a range of mean radial increments and clear bole lengths and with different numbers of crop trees per ha. Hein and Speicker (2009) also promote PCT-based thinning, identifying future crop trees early and thinning to favour their development. Their numbers of final crop trees for ash range from 61 ha^{-1} to 124 ha^{-1}. Tables are provided that show the number of competitors that should be removed per future crop tree; the number of final crop trees per ha; target diameter; crop tree/competitor breast height ratio; and competitor removal data according to crop tree DBH and age. As such, Hein and Spiecker's tables represent one of the most comprehensive attempts since the UK Forestry Commission yield models (Edwards and Christie 1981) to model complete rotations for individual broadleaved species, showing critical crop data over time. In addition, complete rotation tree spacing tables across an increasing DBH range and for different target mean radial increments are provided.

For example, Hein and Spiecker (2009) provide early thinning guidelines for ash which include the removal of between 3 and 5 competitors per PCT. This compares with Irish guidelines for early ash thinning (Short and Radford 2008), which recommend the removal of 2–3 competitors per PCT. However, certain difficulties exist with regard to extrapolating Hein and Spiecker's (2009) models to plantation forestry silviculture outside of their experimental area. Hein and Spiecker base their silvicultural practice for common ash on a "two phase management system", developed by Spiecker (1991) for oak. The pre-thinning first phase involves only natural and intervention pruning until the desired clear bole length is achieved. Phase two then involves successive thinning interventions. The pre-thinning clear-bole lengths for ash considered in the model range from 12–20.3 m. Delaying first thinning to such an extent in Irish ash plantations may compromise the PCT's "competitive status" (as described by Le Goff and Ottorini 1996), i.e. the crown depth as a proportion of overall tree height and therefore the tree's ability to respond to thinning (Kerr and Evans 1993).

Discussion

The principal aim of silvicultural thinning in broadleaf plantations is to ensure satisfactory crown and stem development, and therefore volume increment, of selected PCTs. From an early stage in the rotation, PCT crowns must be kept free from competition to maintain high growth rates and therefore maximise volume increment on the best stems (Kerr and Evans 1993, Savill 2003). This ongoing release of PCT growth is controlled via thinning intensity.

The systems and units employed to control thinning intensity include: basal area (BA) reduction (Çicek et al. 2013), volume removal (Juodvalkis et al. 2005), canopy coverage (Juodvalkis et al. 2005), live crown height as a proportion of stem or tree height (Evans 1984, Le Goff and Ottorini 1996, FRAXIGEN 2005) and stocking or stem removals (Hein and Spiecker 2009). Historically in Irish and UK forestry, publications such as *Thinning Control* (Rollinson 1988) and the *Forestry Commission Yield Models* (Edwards and Christie 1981) provided intensity guidelines based on number of stems per ha, basal area and/or volume removal. In two Irish publications, Joyce et al. (1998) and Short and Radford (2008) provide intensity guidelines based on a reduction of number of stems per ha. Short and Radford (2008) outline the methodology to reduce stocking, including the systematic removal of entire lines of trees (racks), primarily to facilitate access, combined with the selection of PCTs and related competitor removals.

Short and Radford's (2008) recommendations may be contrasted with Hein and Spieker's (2009) thinning control tables, which attach detailed production objectives to the number of competitors removed. In a 15-year-old ash stand, with a PCT DBH of 15 cm, where the DBH of the competitor equates with 90% of the PCT DBH on a 65-year rotation with a target diameter of 60 cm, Hein and Spieker (2009) recommend the removal of 4.3 competitors per PCT ("within the next 5 years" or presumably in a single intervention on a 5-year cycle). This is somewhat heavier than current Irish guidelines suggest. The difficulty in comparison exists in the disparities between geographically distinct silvicultural conditions and practice. Hein and Spieker's (2009) work encompasses a wide range of data and allometric modelling, from a country with a long history of broadleaf silviculture and related research. Within Irish forestry very little allometric data have been available in relation to broadleaf plantations. Therefore, it is difficult to predict how current thinning guidelines will impact PCT development with regard to maintained crown release (in the period to the next thinning). The B-SilvRD programme includes thinning intensity trials, which aim to explore the effects of conventional rack and selective first thinning practice (as recommended by Short and Radford 2008) on PCT development. The early results of these trials would appear to indicate that the volume increment of Irish plantation ash PCTs may be accelerated through heavier selective thinning than was previously thought.

Strong common threads run through all of the reviewed material. Broadleaf thinning should focus on the development of selected individuals. This represents the highest quality stems within the stand, the PCTs. These should be identified early in the rotation. While some highly systematic thinning, such as the removal of lines to facilitate access is accepted, silvicultural thinning should primarily involve the removal of PCT competitors. Crown proportions are closely related to diameter, basal area and volume increment. While different broadleaf species have different rates of crown plasticity, in general PCT crowns should be continually kept free of competition so they can maintain proportions which are able to respond to successive interventions and therefore drive stem and stand volume production.

Thinning intensity is closely related to PCT diameter, basal area and volume increment. Heavier thinnings tend to produce greater/more rapid volume increment. Early thinnings also produce greater/more rapid volume increment. However, Hein and Spiecker (2009) and Juodvalkis et al. (2005) demonstrated there is an upper limit to thinning intensity above, which thinning no longer increasingly benefits PCT development. Heavy thinning may also have a deleterious effect on stem quality, e.g. the production of epicormics in oak, and it may reduce total stand volume production.

The studies reported in this review covered a large geographical area, over which considerable variation in climatic and other environmental conditions, stand dynamics, silvicultural systems etc., might be expected. The research information collected in particular trials may only apply to the provenances used and also the climatic and site conditions of the study area. It may be risky to extrapolate to other sites, especially if located in a different country with different environmental conditions. Such extrapolation requires a degree of speculation possibly not supported by local research; e.g. the minimal stocking thresholds presented by Juodvalkis et al. (2005) may be an underestimate for relatively high YC Irish broadleaf plantations.

Juodvalkis et al. (2005) results do however, provide some very useful observations on the overall effects of thinning broadleaves and therefore may be useful in providing some direction for further thinning intensity trials in different geographic regions. For example, the minimal stocking thresholds outlined may be related to the number of post thinning stems per ha in these trials, which in turn may affect the numbers of PCT competitors removed during thinning. For example, the 30–40% canopy cover minimum stocking figure proposed by Juodvalkis et al. (2005) may correspond to greater than 4 competitors removed per PCT (in a plantation with initial stocking of 2,500 stems ha^{-1} and 1 in 7 lines removed as racks). This is a higher intensity than current Irish guidelines recommend in crop conditions with potentially greater vigour than the continental stands of northern central Europe.

Juodvalkis et al. (2005) state that the "annual increment of the mean DBH was regularly higher, the younger the stand and the larger the spacing," indicating that thinning to favour selected PCTs should be relatively heavy to ensure necessary crown development and rapid DBH increment. While the recommendations of Edwards and Christie (1981) and Rollinson (1988) reflect thinning to marginal intensity, there may be very good silvicultural reasons to thin more heavily and earlier than these thresholds dictate. Indeed, Rollinson (1988) points out certain positive silvicultural and economic aspects of thinning beyond marginal intensity, which will not only produce more rapid diameter increment on good quality PCTs, but it may also make early thinning interventions more profitable through increased thinning yields.

Strong common themes have emerged from recent research into broadleaf thinning. Particularly where the most vigorous, strong light demanding species are concerned, the strongest of these are easily described: "earlier and heavier", i.e. the indications are that these crops may benefit from earlier and heavier thinning than was previously reported. These common themes may therefore be considered, not only in relation to broadleaf thinning guidelines, but also as the basis for further local research trials.

Çicek et al. (2013) demonstrated how a relatively narrow range of treatments, which generally reflects the parameters of normal silvicultural practice, can generate long term results. When expressed in common management units (in this case basal area reduction), it can easily inform practical guidelines.

The literature suggests that top height, threshold BA and proportion of live crown should all be monitored until one or more factors indicate the optimum timing of first (and subsequent) thinning, bearing in mind early is better than late. Competitive status as described by Le Goff and Ottorini (1996) provides an indicative, discernable, formal and recordable description of live crown proportion (in relation to height). Its use is recommended in monitoring broadleaf stands with regard to the timing of thinning interventions. This is particularly true for species such as ash, cherry and birch where successful performance relies on maintaining good live crown proportions relies.

In thinning control, stocking reduction is perhaps the most straightforward means to control thinning operations on the ground, while quantitative PCT selection and appropriate competitor removals can be accurately judged by an experienced eye. Stocking reduction should also be monitored together with a more formal crop inventory descriptor, e.g. basal area.

Conclusions and recommendations

In general, the literature would appear to support the view that relatively high YC broadleaf plantations in Ireland may be thinned more heavily than current guidelines suggest. This is particularly true where the objective is to maximise PCT diameter increment. The upper limit for effective high intensity thinning remains unknown. The intensity regimes employed in international trials (Juodvalkis et al. 2005 and Çicek et al. 2013) were sufficiently broad to fully bracket the expected response to thinning. Future thinning intensity trials in Ireland need to be located primarily in larger, homogenous blocks of vigorous broadleaf plantation. This would facilitate the full replication of a broader range of treatments. Future trials must include significantly heavier thinnings than those included in current guidelines, up to the removal of the entire adjacent eight neighbours. This could be compared with conventional 2–3 competitor removal and begin to identify minimum stocking thresholds as described by Juodvalkis et al. (2005), i.e. the point of maximum acceleration of PCT volume increment.

The concept of maximising volume increment on potentially high value stems is desirable not only for purely economic reasons but may increase resilience to future invasive pests and diseases. For example, the imminent threat to ash woodlands in

Ireland from dieback (Castle 2014) caused by *Hymenoscyphus fraxineus* (Baral et al. 2014) may now present a situation whereby heavy thinning and the securing of crop trees in the shortest possible timeframe may have a range of benefits. From an economic perspective, the window of opportunity for securing a viable return on the investment in Ireland's first rotation ash woodlands may be shortening, wherein the objective of producing high value timber as quickly as possible may be desirable. Thinning in general has been shown to reduce the severity of ash dieback (Bakys et al. 2013). While the impacts of heavier thinning require further research; heavy selective and perhaps more systematic thinning may help to facilitate transitional management objectives such as a change of species via underplanting. It will provide the woodland with a more robust silvicultural and ecological structural composition, to mitigate the impacts of dieback outbreak (Short and Campion 2014). Selection and thinning to favour the most vigorous individuals can also promote the maintenance of the strongest possible genetic population and may assist in the development of resistance (McKinney et al. 2011). Further research on an extensive range of thinning (intensity) treatments in ash must be a short-term priority within Irish broadleaf silviculture and similar research in the longer term is required for other broadleaf species.

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References

Álvarez-González, J.G., Zingg, A. and Gadow, K.V. 2010. Estimating growth in beech forests: a study based on long term experiments in Switzerland. *Annals of Forest Science* 67 (3): p. 307.

Attocchi, G. 2015. Silviculture of Oak for high-quality wood production. Effects of thinning on crown size, volume growth and stem quality in even-aged stands of pedunculate oak (*Quercus robur* L.) in Northern Europe. Doctoral Thesis. *Swedish University of Agricultural Sciences*. Alnarp.

Bakys, R., Vasaitis, R. and Skovsgaard, J.P. 2013. Patterns and severity of crown dieback in young even-aged stands of European ash (*Fraxinus excelsior* L.) in relation to stand density, bud flushing phenotype, and season. *Plant Protection Science* 49: 120–126.

Baral, H.O., Queloz, V.K. and Hosoya, T.S. 2014. *Hymenoscyphus fraxineus*, the correct scientific name for the fungus causing ash dieback in Europe. *IMA Fungus* 5: 79–80.

Barrio Anta, M. and Álvarez González, J.G. 2005. Development of a stand density management diagram for even-aged pedunculate oak stands and its use in designing thinning schedules. *Forestry* 78: 209–216.

Beinhofer, B. 2010. Comparing the financial performance of traditionally managed beech and oak stands with roomy established and pruned stands. *Forest Research* 129: 175–187.

Bolton, Lord 1949. The growth and treatment of sycamore in England. *Quarterly Journal of Forestry* 43: 161–167.

Boncina, A., Kadunc, A. and Dusan, R. 2007. Effects of selective thinning on growth and development of beech (*Fagus sylvatica* L.) forest stands in south-eastern Slovenia. *Annals of Forest Science* 64: 47–57.

Brumme, R., and Khanna, P.K. 2009. *Functioning and Management of European Beech Ecosystems*. Berlin Heidelberg: Springer.

Cameron, A.D. 1996. Managing birch woodlands for the production of quality timber. *Forestry* 69: 357–371.

Castle, M. 2014. Modelling the spread of ash dieback. In *All Ireland* Chalara *Conference – Where do we go From Here?* Proceedings of a conference, held 8th May 2014, Dundalk, Co. Louth. p. 13.

Cescatti, A. and Piutti, E. 1998. Silvicultural alternatives, competition regime and sensitivity to climate in a European beech forest. *Forest Ecology and Management* 102: 213–223.

Çicek, E., Yilmaz, F., Özbayram, A.K., Efe, M., Yilmaz, M. and Usta, A. 2013. Effects of thinning intensity on the growth of narrow-leaved ash (*Fraxinus angustifolia* subsp. *oxycarpa*) plantations. *Turkish Journal of Agriculture and Forestry* 37: 97–104.

Claessens, H. 2004. Réflexions sur le détourage des feuillus à croissance rapide. *Forêt Wallonne* 71: 3–11.

Claessens, H. 2005. L'aulne glutineux. Ses stations et sa sylviculture. *ASBL Forêt Wallonne*.

Department of Agriculture Food and the Marine. 2011. *2010 Annual Report*. Forest Service, Dublin.

Department of Agriculture Food and the Marine. 2012. *2011 Annual Report*. Forest Service, Dublin.

Department of Agriculture Food and the Marine. 2013. *The Second National Forest Inventory, Republic of Ireland, Results*. Forest Service, Johnstown Castle Estate, Co. Wexford.

Department of Agriculture Food and the Marine. 2015. *Ireland's Forests – Annual Statistics*. Forest Service, Johnstown Castle Estate, Co. Wexford.

Department of Communications, Marine and Natural Resources. 2000. *Code of Best Forest Practice - Ireland*. Forest Service, Johnstown Castle Estate, Co. Wexford.

Dimov, L.D., Stelzer, E., Wharton, K., Meadows, J.S., Chambers, J.L., Ribbeck, K. and Moser, E.B. 2006. Effects of thinning intensity and crown class on cherrybark oak epicormic branching five years after treatment. In *Proceedings of the 13th*

Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS–92. Ed. Connor, K.F., Asheville, NC, U.S. Department of Agriculture, Forest Service, Southern Research Station, p. 640.

Dobrowolska, D., Hein, S., Oosterbaan, A., Wagner, S., Clark, J. and Skovsgaard, J.P. 2011. A review of European ash (*Fraxinus excelsior* L.): implications for silviculture. *Forestry* 84: 133–148.

Duyck, D. 1997. Guide de sylviculture merisier en region Normande. Cited in Boulet-Gercourt, B. 1997. *Le Merisier. Les Guides du Sylviculteur.* IDF.

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

Evans, J. 1982. Silviculture of oak and beech in northern France: observations and current trends. *Quarterly Journal of Forestry* 76: 75–81.

Evans, J. 1984. *Silviculture of Broadleaved Woodland*. Forestry Commission Bulletin 62. HMSO, London.

Everard, J.E. 1985. *Management of Broadleaved Forests in Western Europe*. Report of a three-month study visit to France, and four other countries. Forestry Commission, Edinburgh.

Fällman, K., Ligne, D., Karlsson, A. and Albrektson, A. 2003. Stem quality and height development in a *Betula*-dominated stand seven years after precommercial thinning at different stump heights. *Scandinavian Journal of Forest Research* 18: 145–154.

Forestry Commission. 1955. *The Thinning of Plantations*. Forestry Commission Forest Operations Series No. 1. HMSO, London.

FRAXIGEN. 2005. *Ash species in Europe: biological characteristics and practical guidelines for sustainable use*. Oxford Forestry Institute, University of Oxford, UK. p. 128.

Government of Ireland. 2013. *The Second National Forest Inventory, Republic of Ireland, Results*. Forest Service: Johnstown Castle Estate, Co. Wexford.

Hallenbarter, D., Hasenauer, H. and Zingg, A. 2005. Validierung des Waldwachstums-modells MOSES für Schweizer Wälder. *Schweizerische Zeitschrift für Forstwesen* 156: 149–156. Cited in Álvarez-González, J.G., Zingg, A. and Gadow, K.V. 2010. Estimating growth in beech forests: a study based on long term experiments in Switzerland. *Annals of Forest Science* 67: p. 307.

Hamilton, G.J. 1976. The Bowmont Norway spruce thinning experiment 1930–1974. *Forestry* 49: 109–19.

Hamilton, G.J. 1981 The effects of high intensity thinning on yield. *Forestry* 54: 1–15.

Hart, C. 1991 *Practical Forestry for the Agent and Surveyor*. 3rd ed. Sutton Publishing, Stroud.

Hawe, J. 2014. *Early Thinning of Ash*, Fraxinus excelsior *L., Plantations in Ireland –*

Thinning Intensity and Crop Tree Growth Responses. Masters Thesis. University College Dublin.

Hawe, J. and Short, I. 2012. Poor performance of broadleaf plantations and possible remedial silvicultural systems - a review. *Irish Forestry* 69: 126–147.

Hein, S., Collet, C., Ammer, C., Le Goff, N., Skovsgaard, J.P. and Savill, P. 2009a. A review of growth and stand dynamics of *Acer pseudoplatanus* L. in Europe: implications for silviculture. *Forestry* 82: 361–385.

Hein, S. and Spiecker, H. 2009. Controlling diameter growth of common ash, sycamore maple and wild cherry. *European Journal of Forest Research* 22: 123–147.

Hein, S., Winterhalter, D., Wilhelm, G.J. and Kohnle, U. 2009b. Timber production with silver birch (*Betula pendula* Roth): Chances and silvicultural constraints. *Allgemeine Forst Und Jagdzeitung* 180: 206–219.

Hemery, G.E., Savill, P.S. and Pryor, S.N. 2005. Applications of the crown diameter-stem diameter relationship for different species of broadleaved trees. *Forest Ecology and Management* 215: 285–294.

Hendrick, E. and Nevins, D. 2003. Foreword to *Managing Our Broadleaf Resource to Produce Quality Hardwood Timber*. Eds. Fennessy, J. and MacLennan, L., Proceedings of the COFORD seminar 10 – 11th October 2002, Carrick-on-Shannon. COFORD, Dublin.

Hiley, W.E. 1955. The thinning of plantations. *Irish Forestry* 12: 3–11.

Hill, M.O., Mountford, J.O., Roy, D.B. and Bunce, R.G.H. 1999. *Ellenberg's Indicator Values for British Plants. ECOFACT Volume 2 Technical Annex*. Huntingdon, Institute of Terrestrial Ecology, p. 46.

Hochbichler, E. 1993. Methods of oak silviculture in Austria. *Annals of Forest Science* 50: 583–591.

Horgan, T., Keane, M., McCarthy, R., Lally, M. and Thompson, D. 2003. *A Guide to Forest Tree Species Selection and Silviculture in Ireland*. Ed. O'Carroll, J., COFORD, Dublin.

Hummel, F.D. 1951. Increment of "free-grown" oak. *Report on Forest Research*, Forestry Commission, London, p. 65–66. Cited in Evans, J. 1982. Free growth and control of epicormics. In *Broadleaves in Britain*. Eds. Malcolm, D.C., Evans, J. and Edwards, P.N., Proceedings of a symposium, Loughborough, Leicestershire, 7 – 9th July 1982. The Institute of Chartered Foresters, pp. 183–190.

Hynynen, J. and Niemistö, P. 2009. *Silviculture of Silver Birch in Finland*. http://www.waldwissen.net/lernen/weltforstwirtschaft/fva_birke_waldbau_finnland/index_EN [Retrieved May 2015].

Hynynen, J., Niemistö, P., Viherä-Aarnio, A., Brunner, A., Hein, S. and Velling, P. 2009. Silviculture of birch (*Betula pendula* Roth and *Betula pubescens* Ehrh.) in northern Europe. *Forestry* 83: 103–119.

Jobling, J. and Pearce, M.L. 1977. *Free Growth of Oak*. Forestry Commission Forest Record 113: 1–17.

Joyce, P., Huss. J., McCarthy, R., Pfeifer, A. and Hendrick, E. 1998. *Growing Broadleaves – Silvicultural Guidelines for Ash, Sycamore, Wild Cherry, Beech and Oak in Ireland*. COFORD, Dublin.

Juodvalkis, A.A., Kairiukstis, L. and Vasiliauskas, R. 2005. Effects of thinning on growth of six tree species in north-temperate forests of Lithuania. *European Journal of Forest Research* 124: 187–192.

Kerr, G. 1996. The effect of heavy or "free growth" thinning on oak (*Quercus petraea* and *Q. robur*). *Forestry* 69: 303–317.

Kerr, G. and Cahalan, C. 2004. A review of site factors affecting the early growth of ash (*Fraxinus excelsior* L.). *Forest Ecology and Management* 188: 225–234.

Kerr, G. and Evans, J. 1993. *Growing Broadleaves for Timber*. Forestry Commission Handbook 9. HMSO, London.

Le Goff, N. and Ottorini, J.M. 1996. Leaf development and stem growth of ash *(Fraxinus excelsior)* as affected by tree competitive status. *Journal of Applied Ecology* 33: 793-802.

Lemaire, J. 2010. *Le Chêne Autrement. Produire du Chêne de Qualité en Moins de 100 Ans en Futaie Régulière. Guide Technique*. Forêt Privée Françoise.

Liepiņš, K., Baumanis, I., Gailis, A. and Aļļis, J. 2011. *Management and Stand Dynamics of Birch Forests: a Reflection on Shifting Silvicultural Concepts in Latvia*. In Proceedings of the Fifth International Scientific Conference: Rural Development. 22–25th November, 2011. Aleksandras Stulginkis University, Kaunas, Lithuania, p. 69.

Lockhart, B.R., Michalek, A.J. and Lowe, M.W. 2006. *Epicormic Branching in Red Oak Crop Trees Five Years After Thinning and Fertilizer Application in a Bottomland Hardwood Stand*. In Proceedings of the 13th biennial southern silvicultural research conference. Ed. Connor, K.F. Gen. Tech. Rep. SRS–92. Asheville, NC, U.S. Department of Agriculture, Forest Service, Southern Research Station, p. 640.

Loewe, V.M., González, M.O. and Balzarini, M. 2013. Wild cherry tree (*Prunus avium* L.) growth in pure and mixed plantations in South America. *Forest Ecology and Management* 306: 31–41.

Lorrain-Smith, R. and Worrell, R. 1992. The commercial potential of birch in Scotland. *Scottish Forestry* 46: 48–55.

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

Mielikäinen, K., Hynynen, J., Niemistö, P., Viherä-Aarnio, A., Brunner, A. and Hein, S. 2007. *Ecology and Management of Silver Birch (*Betula pendula *Roth.)*. ValBro

– Growing Valuable Broadleaved Tree Species COST Action. Presentation given in Finland (10–14th June 2007).

Mitchell, K.J. 1975. Dynamics and simulated yield of Douglas-fir. *Forest Science* Monograph 17. Society of American Foresters.

Nagel, J. 1985. *Wachstumsmodell für Bergahorn in Schleswig-Holstein*. Dissertation. Universität Göttingen. Cited in Hein, S., Collet, C., Ammer, C., Le Goff, N., Skovsgaard, J.P. and Savill, P. 2009. A review of growth and stand dynamics of *Acer pseudoplatanus* L. in Europe: implications for silviculture. *Forestry* 82: 361–385.

Nieuwenhuis, M. and Barrett, F. 2002. The growth potential of downy birch (*Betula pubescens* (Ehrh.)) in Ireland. *Forestry* 75: 75–87.

Nisbet, J. 1893. *British Forestry Trees and their Sylvicultural Characteristics and Treatment*. Macmillan and Co., London.

O'Dowd, N. 2004. *The Improvement of Irish Birch. Phase 1: Selection of Individuals and Populations*. COFORD: Dublin.

Ottorini, J.-M. 1991. Growth and development of individual Douglas-fir in stands for applications to simulation in silviculture. *Annales des Sciences Forestieres* 48: 651–666.

Ottorini, J.M., Le Goff, N. and Cluzeau, C. 1996. Relationships between crown dimensions and stem development in *Fraxinus excelsior* L. *Canadian Journal of Forest Research* 26: 394–401.

Pakenham, R. 2005. *Growing Valuable Broadleaved Tree Species: Silvicultural Perspective*. ValBro – Growing Valuable Broadleaved Tree Species COST Action. Presentation given in Thessaloniki (18th - 21st May 2005).

Pautasso, M., Petter, F., Rortais, A. and Roy, A.S. 2015. Emerging risks to plant health: a European perspective. *CAB Reviews* 10.

Plauborg, K.U. 2004. Analysis of radial growth responses to changes in stand density for four tree species. *Forest Ecology and Management* 188: 65–75.

Poulain, G. 1991. Quelques examples de la sylviculture de l'aulne glutineux en Thiérache (Nord de l'Aisne). *Forêt Entreprise* 74: 26–28.

Pretzsch, H. 2005. Stand density and growth of Norway spruce (*Picea abies* (L.) Karst.) and European beech (*Fagus sylvatica* L.): evidence from long-term experimental plots. *European Journal of Forest Research* 124: 193–205.

Pryor, S.N. 1985. The silviculture of wild cherry or gean (*Prunus avium* L.). *Quarterly Journal of Forestry* 79: 95–109.

Pryor, S.N. 1988. *The Silviculture and Yield of Wild Cherry*. Forestry Commission Bulletin 75. HMSO, London.

Raulo, J. 1987. *Bojrkboken Oversatt av Fritz Bergman*. Skogsstyrelsen, Jonkoping. Cited in Cameron, A.D. 1996. Managing birch woodlands for the production of quality timber. *Forestry* 69: 357–371.

Renou, F., Scallan, Ú., Keane, M. and Farrell, E.P. 2007. Early performance of native birch (*Betula* spp.) planted on cutaway peatlands: influence of species, stock types and seedlings size. *European Journal of Forest Research* 126: 545–554.

Rollinson, T.J.D. 1988. *Thinning Control*. Forestry Commission Field Book 2. HMSO, London.

Rytter, L. and Werner, M. 1998. *Lönsam lövskog—Steg för steg* [Profitable broadleaved forests—Step by step]. Uppsala, Forestry Research Institute of Sweden (SkogForsk), Handledning. (In Swedish). Cited in Rytter, L. and Werner, M. 2007. Influence of early thinning in broadleaved stands on development of remaining stems. *Scandinavian Journal of Forest Research* 22: 198–210.

Rytter, L. and Werner, M. 2007. Influence of early thinning in broadleaved stands on development of remaining stems. *Scandinavian Journal of Forest Research* 22: 198–210.

Savill, P. 2003. *Growing Quality Broadleaves – the British Experience*. In Managing our broadleaf resource to produce quality hardwood timber. Eds. Fennessy, J. and MacLennan, L., Proceedings of the COFORD seminar 10–11th October 2002, Carrick-on-Shannon. COFORD, Dublin.

Savill, P.S. 2013. *The Silviculture of Trees Used in British Forestry*. CAB International, Wallingford.

Savill, P., Evans, J., Auclair, D. and Falck, J. 1997. *Plantation Silviculture in Europe*. Oxford University Press, Oxford.

Schröter, M., Härdtle, W. and von Oheimb, G. 2012. Crown plasticity and neighborhood interactions of European beech (*Fagus sylvatica* L.) in an old-growth forest. *European Journal of Forest Research* 131: 787–798.

Sevrin, É. 1997. *Les Chênes Sessile et Pédonculé*. Les Guides du Sylviculteur. Institut Pour Le Développement Forestier.

Shapland, R.E. 1966. Notes on the establishment and early thinnings in oak plantations. *Quarterly Journal of Forestry* 60: 55–57.

Short, I. and Campion, J. 2014. Management of ash in the light of chalara dieback. In *All Ireland* Chalara *Conference – Where do we go From Here?* Proceedings of a conference, held 8th May 2014, Dundalk, Co. Louth, p. 14.

Short, I. and Radford, T. 2008. *Silvicultural Guidelines for the Tending and Thinning of Broadleaves*. Teagasc.

Skovsgaard, J.P., Nordfjell, T. and Sørensen, I. H. 2006. Precommercial thinning of beech (*Fagus sylvatica* L.): Early effects of stump height on growth and natural pruning of potential crop trees. *Scandinavian Journal of Forest Research* 21: 380–387.

Sonderman, E.L. and Rast E.D. 1988. *Effect of Thinning on Mixed-Oak Stem Quality*. Res. Pap. NE-618. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, p. 6.

Spiecker, H. 1991. Zur Steuerung des Dickenwachstums und er Astreinigung von Trauben - und Stieleichen (*Quercus petrea* (Matt.) Liebl. und *Quercus robur* L.) [On the controlling of diameter growth and natural pruning of Sessile and Pedunculate Oak (*Quercus petrea* (Matt.) Liebl. and *Quercus robur* L.)]. Schriftenreihe der Landesforstverwaltung Baden-Wurttemberg 72. Stuttgart [original in German]. Cited in Hein, S. and Spiecker, H. 2009 Controlling diameter growth of common ash, sycamore maple and wild cherry. *European Forest Institute Research Report* 22: 123–147.

Štefančík, I. 2013. Development of target (crop) trees in beech (*Fagus sylvatica* L.) stand with delayed initial tending and managed by different thinning methods. *Journal of Forest Science* 56: 253–259.

Štefančík, I. 2015. The effect of different tending on stand structure and quantitative production of European beech (*Fagus sylvatica* L.) stand in a selected region of East Slovakia. *Journal of Forest Science* 61: 98–105.

Stern, R.C. 1989. Sycamore in Wessex. *Forestry* 62: 365–382.

Stevenson, G.F. 1985. *The Silviculture of Ash and Sycamore*. Proceedings of the National Hardwoods Programme. Commonwealth Forestry Institute, Oxford, pp. 25–31.

Stojecová, R. and Kupka, I. 2009. Growth of wild cherry (*Prunus avium* L.) in a mixture with other species in a demonstration forest. *Journal of Forest Science* 55: 264–269.

Teagasc. 2015. https://www.teagasc.ie/crops/forestry/research/broadleaf-silviculture-research-and-development/ [Accessed November 2016].

Vaast, V. and Billac, J.M. 1996. Quelle sylviculture pour l'aulne glutineux? *Forêt de France* 397: 22–27.

Van der Maaten, E. 2013. Thinning prolongs growth duration of European beech (*Fagus sylvatica* L.) across a valley in southwestern Germany. *Forest Ecology and Management* 306: 135–141.

Worrell, R. 1999. *The Birch Woodland Management Handbook*. Highland Birchwoods: Ross-shire.

Zālītis, T. and Zālītis, P. 2007. Growth of young stands of silver birch (*Betula pendula* Roth) depending on pre-commercial thinning intensity. *Baltic Forestry* 13: 61–67.

Zeide, B. 2006. Evolution of silvicultural thinning: from rejection to transcendence. In *Proceedings of the 13th Biennial Southern Silvicultural Research Conference*. *General Technical Report SRS-92*. Ed. Connor, K.F., Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station, pp. 322–327.

A review of the range and value of ecosystem services from Irish forests

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Abstract

Much reference is made to the importance of forests in the delivery of ecosystem services. This paper examines the range of biophysical services provided by forests and the economic and social value of the final ecosystem services. Although information is presented for Ireland where just over one tenth of the land area is forest, most of which is comprised of planted conifer species with a smaller proportion of broadleaf species, this composition is comparable to that of many other developed countries with a temperate climate. The assessment examines the evidence for ecosystem services in relation to habitat, timber production, carbon storage and sequestration, water quality, moderation of run-off, recreation and amenity. It distinguishes between the services provided by forests as distinct from trees and takes into account alternative uses of the land, the role of soils and the contribution of appropriate management to avoiding potentially adverse impacts. It aims to provide a comprehensive, if introductory review of the range of ES, the interactions that exist between them, their economic value and the opportunities for forest policy and management to strengthen these benefits.

Keywords: *Forest, carbon sequestration, water, amenity, biodiversity, economic value*.

Introduction

In 2012, the European Union adopted a Biodiversity Strategy (EU 2011) that aims to halt the loss of biodiversity and ecosystem services (ES) by 2020. As an essential step towards this aim, the strategy requires that Member States map and estimate the value of ES. For forests, this objective had been expressed at the Oslo meeting of the Ministerial Conferences on the Protection of Forests in 2011 and has been followed up in subsequent expert group reports. (Forest Europe 2014).

This paper discusses the principal ES that are provided by forests and the extent to which these are realised in Ireland where much forest consists of planted commercial species. As such, the paper is of relevance to other countries with a temperate climate where forests have been planted for wood production, but which also possess some areas

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of native species forest. The paper includes also economic estimates of the ES value and explores the influence of forest management and composition on the flow of these services.

Ecosystem services

The Millennium Ecosystem Assessment (MEA 2005) defines ES as the benefits that people obtain from natural ecosystems. Forests contribute a range of important ES including habitat for biodiversity, timber and forest products, climate change mitigation, erosion protection, catchment protection, and amenity and recreation. The relative value that people place, directly or indirectly, on these ES has varied over time. In Ireland, previous generations would have placed a particular value on forests for fuel and materials. However, the supply of all ES was compromised by extensive deforestation from the fifteenth century to the beginning of the twentieth century by which time forest accounted for just 1% of land area. That area has now risen to 10.5% due to the planting of mostly non-native conifers for which Ireland has a very suitable climate. These trees have mainly been planted for timber and 83.7% of the planted area is now available for this purpose according to the National Forest Inventory (Forest Service 2012). Conifer plantation accounts for 472,752 ha with the remainder comprising largely mixed and non-native broadleaf species, including commercial broadleaf plantings. Around 164,000 ha are comprised mostly of broadleaf tree species (DAFM 2014) of which just 100,000 ha are regarded as being native species woodland with 20,000 ha being defined as ancient woodland, i.e. woodland dating from before the 1600s (Perrin and Daly 2010). Figure 1 illustrates the distribution of forests in Ireland and Table 1 lists some of the key characteristics of these forests.

While Ireland still has a low proportion of its land area covered by forest compared to other European states, the characteristics of its forests, and the associated ES, do resemble those of other countries that have sought to increase their forest area through commercial afforestation. Globally, the area of plantation forest continues to increase and surpassed 264 million ha in 2010. By comparison, 13 million ha of natural forest is being lost each year, representing a net loss of 5.2 million ha of forest (FAO 2010).

Although planted forests provide their own set of ES, these services do replace those associated with previous land uses. In common with some other countries, most afforestation in Ireland has occurred on lands of marginal agricultural value (Upton et al. 2014; Smith et al. 2006) with the support of afforestation grants and premiums. These areas have included low-intensity upland farmland and, until recently, peatlands (Renou-Wilson and Byrne 2015), both of which can have a high ES or biodiversity value. Irish Forest Service grants are now restricted to cultivable land and support for planting on unimproved land is restricted to no more than 20% of the total area[1]. This paper addresses the net impact of forestry where grown on lands of both high and low ES value.

[1] The Forest Schemes Manual (Appendix 14 –Land Types for Afforestation) excludes designated and infertile raised or blanket bog and unmodified raised bog.

Methodology

The paper undertakes a comprehensive review of the evidence for ES benefits in Ireland's forests. It draws on research published in the fields of forestry science, land use change, soil science, ecology and hydrology to demonstrate the extent of ES flows under different conditions or in different locations. The review distinguishes the ES provided by different types of trees, individual or small numbers of trees, and trees growing in forests. It also considers the implications of forest planting regulations and management. Where possible it applies an economic value to ES benefits which may be captured by market processes or represented by non-market values. In the latter case, various methods are available to demonstrate these values, including cost-based methods, revealed or stated preference, and value transfer.

a) Ecosystem service provision.

b) Classifications.

c) The MEA (2005) identified four types of ES, namely:
   - i) provisioning services, i.e. the products obtained from ecosystems;
   - ii) regulating services, i.e. benefits obtained from the maintenance and regulation of ecosystem processes;
   - iii) cultural services, i.e. the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences; and
   - iv) supporting services, i.e. those that are necessary for the production of all other ES.

Although the MEA was an important step in the overview of global ES, classification systems are not definitive and continue to evolve as our understanding of ES increases (Fisher et al. 2009). The Common International Classification of Ecosystem Services (CICES 2013) was prepared on behalf of the European Environment Agency to assist with biodiversity accounting and is now the principal classification used by researchers and policy makers. CICES acknowledges the contribution of ecological structures and processes in supporting final ES, but places the focus on the relationship between provisioning, regulating and cultural ES as final services that supply goods and benefits for human well-being. In this way, the risk of double-counting of benefits is minimised. The flow of these services from the biophysical environment to the human environment is represented by the Cascade Model (Haines-Young and Potschin 2010, Potschin and Haines-Young 2011) in Figure 1.

Various studies have demonstrated the public good value of Ireland's forests, including Ní Dhubháin et al. (1994), Clinch (1999), Scarpa et al. (2000), Fitzpatrick

Figure 1: *Forest distribution in Ireland.*

Table 1: *Some principal characteristics of Irish forests.*

Ownership		**Area (ha)**
Public forests		389,356
Private forests:	grant aided	248,554
	other	93,742
Species composition		**Area (ha)**
Conifer		436,980
Broadleaf		111,340
Mixed species		88,810
Other, e.g. temporarily unstocked, open areas, etc		94,522
Total		731,652

Associates (2005), Howley et al. (2011) and Upton et al. (2012). Irish forest policy acknowledges the diverse services that forests provide. Its strategic goal is to develop an internationally competitive and sustainable forest sector that provides a full range of economic, environmental and social benefits to society and which accords with the Forest Europe definition of sustainable forest management (DAFM 2014).

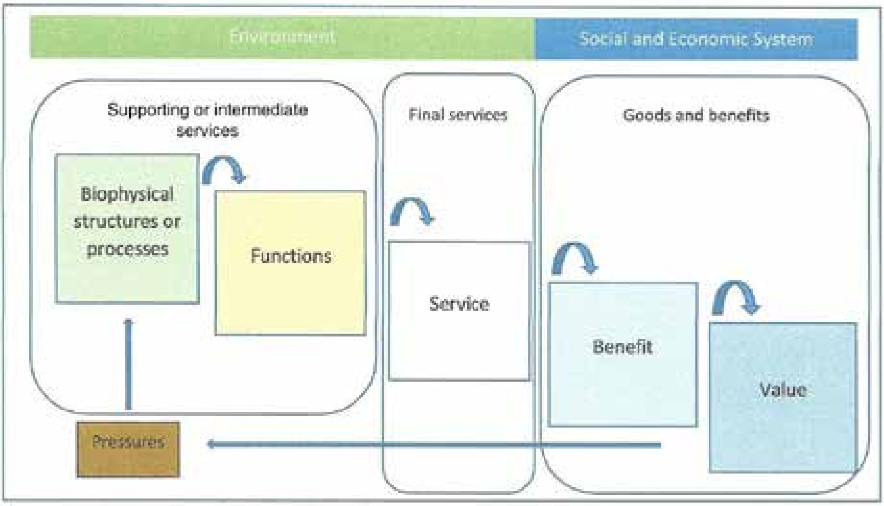

Figure 2: *The cascade model of ecosystem services (after Haines-Young and Potschin 2011).*

Criteria and funding mechanisms have therefore been set to achieve appropriate afforestation and management. Receipt of funding is conditional on the inclusion of a minimum 10% area of broadleaf species and a biodiversity enhancement area[2]. However, an ecosystem approach that seeks to maximise these benefits has not been explicitly adopted to date.

Provisioning services

Provisioning services relate to many of the most familiar and tangible benefits that forests provide, namely wood and non-wood products. The management of forests to supply these products can be complimentary to the supply of other ES, but the net benefits will depend on where and what trees are planted, including the intensity of production, use of chemical inputs and mix of tree species.

The overall value of the forestry sector to the Irish economy is estimated at €2.3 billion of which the net contribution to gross domestic product from growing and harvesting is put at €137 million (DAFM 2014). As an ES, timber production is best understood in terms of harvest volumes. Annual roundwood production from Irish forests has ranged between 2.8-3.0 million m^3 in recent years (O'Driscoll 2014). The price of wood products covers labour and capital inputs added during the harvesting and processing stages. Therefore to avoid double counting, the value of the core provisioning service is best represented by that of the standing crop less the cost of the capital, and labour inputs needed during ground preparation, planting and subsequent management[2].

[2] According to the Irish afforestation scheme.
[3] The cost of these inputs is largely offset by establishment grants of €2,000 to €5,000 ha^{-1}.

In Ireland, this production mainly enters the domestic sawmilling sector which relies largely on softwoods to produce construction and lower grade timber products. The average standing timber price for 2015[4] was €59 m^{-3}. By comparison, quality hardwood currently attracts prices of €100 per m^3 or more for use in the craft sector, furniture and interior decoration. The very limited supply of Irish hardwoods means that this value is usually realised by imported hardwoods[5]. However, the increasing area of broadleaf will increase future supplies. The Forest Policy Review also identifies the potential to make greater use of small diameter hardwoods.

Fuelwood or biomass is another outlet for harvested products that has grown substantially in recent years. Due to the interest in renewable energy and the periodically high price of oil, demand for biomass for heat and energy is now estimated at 800,000 m^3 per annum. Wood-based biomass is equal to 34% of domestic production with the market estimated to be worth €33 million per year (Knaggs and O'Driscoll 2013). These market returns have provided an incentive for renewed management of many private woodlands, specifically thinning (Bullock and Hawe 2013).

As well as wood products, forests supply supplementary products such as berries, nuts, edible fungi, foliage and game (Harrington and Cullen 2008, Bastrup-Birk et al. 2011, Collier et al. 2004). While these outputs can be an important provisioning service benefit, they are relatively minor in Ireland (although the value of foliage production has been estimated at €2.5 million (Ní Dhubháin et al. 2012)). Deer are shot for management purposes and sport providing income through hunting leases and client fees, but there are no estimates of the amount of game that enters the food chain. The expansion of commercial forest has led to an explosion in the population of deer and around 25,000 deer were culled in Irish forests in 2009 (Purser et al. 2009), suggesting a possible value of €1.2-€2.3 million per year[6]. Culling is extremely difficult in young plantations and has been inadequate to prevent continued tree damage. In entirely natural circumstances, deer would themselves provide regulating ES, and their numbers would be kept in check by predators. Without fencing and active management of the growing deer population, browsing could significantly reduce the regeneration and value of forests, including other ES values. For conifer forests, financial losses have been estimated as being as much as 22%, i.e. up to €3,800 ha^{-1} and potentially more for broadleaf (Purser et al. 2009).

[4] Taken from Teagasc website (https://www.teagasc.ie/crops/forestry/advice/markets/timber-sales-and-prices-index/).

[5] Timber prices are available from the state forest company, Coillte, and the Forestry Yearbook, but hardwood supplies are currently sporadic and prices were obtained through consultation with three milling companies.

[6] At average market values assuming 50 kg carcass and 60% allowance for waste.

Regulating and maintenance services

Nature of regulating services

Forests provide a range of regulating and maintenance services, although these vary depending on the forest environment, for example, plantation, species, native, age, area, etc. Regulating services are amongst the most challenging ES to quantify. Many regulating services relate to ecosystem processes that influence the manner and rate at which trees grow. This means that there is a particular need to avoid double-counting in that many of these services are intermediate, contributing also to provisioning and cultural services. For example, ES involved in soil formation and the decomposition and recycling of organic matter are critical to supplying the nutrients needed for tree growth. The value of these services is captured by the standing value of trees grown for commercial harvest but is also reflected in a range of ES benefits provided by forests in general. Among the most valuable regulating services that are not captured by the commercial value of the trees are carbon sequestration and storage, the contribution to water quality and the moderation of run-off (Howley et al. 2014). Trees also provide a regulating service by moderating temperature (Bolund and Hunhammer 1999) and noise levels (Leonard and Parr 1970), by intercepting airborne particulates or by reducing sulphur dioxide and ozone (Powe and Willis 2002). The value of these ES is highest in cities where individual trees and community woodlands can provide ES benefits to a large population along with significant amenity or recreational benefits (Gomez-Baggethun and Barton 2012). However, most forests, including those in Ireland, are grown in rural areas with relatively low populations, noise and pollution.

Carbon sequestration and storage

The sequestration and storage of carbon by forests are fundamental to climate regulation. Key factors are the rate of growth and the maturity of the trees. In Ireland, the majority of commercial plantings are in their growth phase such that active sequestration is a particular feature of the Irish forest estate relative to other countries with more mature forest. Carbon sequestration by forests is largely determined by gross primary productivity and, as such, is strongly influenced by growth rates, species and management (Chen et al. 2014). In Ireland, most sequestration is due to commercially grown conifers which represent the largest proportion of the total forest estate. The very small area of native species forest consists almost entirely of mature broad-leaf species for which carbon storage is the more relevant factor (Bullock et al. 2014).

In principle, it is the forest soils, or more specifically the biomass of organisms and organic debris, that are the more important carbon pool as these account for 85% of the forest carbon store (Forest Service 2013)[7]. Much of this store will have accumulated

[7] On average, woody biomass amounts to 12.7% of the carbon store, of which 10.4% is above ground and 2.3% below ground. The remaining carbon is found in the leaf litter (1.6%) and deadwood (0.6%) (Forest Service 2013).

over a long period of time or under previous land cover. Once forested, more carbon is accumulated in the soil than for permanent grassland or, especially, for arable use which tends to result in net losses of carbon (Gobin et al. 2011).

The initial preparation of land for tree planting can result in the oxidation of soil organic matter and carbon losses. However, it is now a requirement that forests are replanted so that disturbance of the soil is minimised along with carbon losses especially when existing seed sources are used. Initial losses are highest for peat based soils on which many older forests were planted and which account for 46% of the forest estate in Ireland. Although much carbon would have already been released from these locations when originally drained or cut for domestic and industrial fuel, others would have been under rough grazing and have retained a significant store of carbon. The net carbon balance (i.e. between carbon uptake and loss) is likely to be highly variable across a range of temporal and spatial scales as a result of factors such as soil type, species, age and management. Research by Hargreaves et al. (2003) in Scotland found that forests on peat soils become net carbon sinks 4-8 years after planting. On the other hand, samples taken from streams and lakes in the west of Ireland indicate substantial losses of both particulate and dissolved organic carbon (DOC) from forested peatlands amounting to 0.10 t C ha^{-1} yr^{-1} and 0.62 t C ha^{-1} yr^{-1} year (Ryder et al. 2014), adding to the risk of acidification and loss to the atmosphere. Feely et al. (2014) and Kelly-Quinn et al. (2016) have also reported that DOC in streams draining peaty soils in Ireland is significantly higher than those in non-forested moorland. Excluding this factor, Irish forests are estimated to be a carbon store of 57 million tonnes (DAFM 2012) and to be net carbon sinks responsible for sequestering 4-8 t C ha^{-1} yr^{-1} (Black and Farrell 2006).

Sequestration by planted forests effectively buys time for society to begin to agree to reductions in greenhouse gas emissions (GHG). This ES benefit is realised at a global level, but carbon sequestration has been a factor in allowing Ireland to be compliant with emissions targets for the first Kyoto commitment period (2008-2012) and can help to offset future emissions in line with EU policy (NESC 2012). The young age of much of Ireland's forest is relevant in this regard as only sequestration by forests planted after the 1990 baseline counts towards the national target (Black and Farrell 2006, McGettigan 2009, Byrne 2010). The post 1990 portion of the estate accounts for over 40% of the 731,650 ha forest estate (Forest Service 2013). As of 2014, carbon sequestration by these trees (less deforestation) amounted to 3.5 M t CO_2 eq yr^{-1}. Trees planted prior to 1990 do not contribute to Ireland's international mitigation obligations, but nevertheless provide for net sequestration. Sequestration at 45 years is estimated at just over 75% of that for trees of 15 years (after Tobin et al. (2006) allowing for the lower density of older stands).

The use to which felled timber is put is relevant to estimating the carbon balance too. Harvested wood products are an important carbon pool (Donlan et al. 2012). Close to 40% of the total volume of felled timber goes to construction-related uses where its longevity is extended and the carbon consequently locked up for decades. However, the aforementioned increase in demand for wood for bioenergy now accounts for between one third and half of the annual harvest of wood products (Knaggs and O'Driscoll 2013, Phillips 2011, UNECE/FAO 2013). Nevertheless, this use helps to offset emissions from fossil fuel use. If this latter proportion is excluded, net sequestration by post 1990 plantings is estimated at 3.1 M t CO_2 eq yr^{-1} for 2014 once net harvesting and management is taken into account[8]. Total sequestration by the forest estate is estimated[10] to be 6.9 M t CO_2 eq yr^{-1}.

There are three main ways of quantifying carbon sequestration in economic terms, namely:

- the social value of future climate change;
- the traded price of carbon;
- the marginal abatement cost of energy conservation or of switching to alternative fuels.

In principle, estimates of the social value of sequestration would be most relevant as these reflect reductions in the future cost of climate change (Pearce 2003). However, estimates of these costs are subject to tremendous uncertainty (Bellard et al. 2012, Millar et al. 2007, Walther 2010, Tol 2005). Alternatively, the traded price of carbon on the European Emissions Trading Scheme (ETS) can be used as a proxy for social value[9]. This approach is recommended by Public Spending Code guidance[11]. However, prices are subject to exogenous factors such as current economic growth and trading permit criteria. Policy decisions markedly influence supply/demand factors, and these current factors undermine the usefulness of ETS prices for valuing long-term carbon sequestration (Guitart and Rodriguez 2010). In 2014, for instance, the carbon price on the ETS averaged €7 per tonne. While this price had been expected to rise as the international economy recovered, this has not happened due a combination of sluggish growth and political disagreement.

An alternative approach to quantifying the economic benefits of carbon sequestration is to take the marginal abatement cost of energy conservation or switching. For the UK, McKinsey (2007) has estimated this cost as a much higher figure than the ETS price at up to €90 t CO_2, falling to €40 t CO_2 as more abatement options become available. The approach is still subject to uncertainty with regard to

[8] Forest Service submission: Information on LULUCF actions to limit or reduce emissions and maintain or increase removals from activities defined under Decision 529/2013/EU.

[9] These figures refer to the trees only and do not include net carbon storage in the soils.

[10] Other greenhouse gases can be converted to an equivalent price using IPCC conversion factors for Global Warming Potential.

[11] Available at http://publicspendingcode.per.gov.ie/wp-content/uploads/2015/09/E5.pdf (accessed October 2016).

the availability or type of abatement, but does provide a reasonable representation of the current cost of mitigation. On the basis of an abatement curve supplied for Ireland by Motherway and Walker (2009), an average value post-2014 of €39 t CO_2 has been adopted post-2014 by Ireland's Department of Finance. Given the estimates above for total sequestration, this would imply that Irish forests are sequestering over €260 million worth of carbon per year, although the actual value is at any one time is influenced by prevailing international emission targets.

Water flow regulation

Through their uptake, transport and apportioning of water, forests have an inherent ability to regulate the volume of water entering rivers, lakes and reservoirs. Although forests have been linked to reduced aquifer recharge or surface runoff (van Dijk and Keenan 2007, Farley et al. 2005), water shortage is rarely a problem in Ireland (Allen and Chapman 2001). Rather, reductions in surface runoff from forested areas provide an ES by potentially reducing the incidence or severity of downstream flooding (Bradshaw et al. 2007, Thomas and Nisbet 2007). Trees and ground cover intercept rainfall and evapotranspiration is higher than for other land uses (Zhang et al. 2001). Forest soils also act as a sponge, infiltration is greater and water is released more slowly into streams, extending and delaying peak flows (Calder et al. 2002, Laurance 2007, Nisbet and Thomas 2006) This means that forests can mitigate catchment scale flash flooding events (Robinson et al. 2003, Calder 2007, FAO 2005) of the type that often cause most material damage, although the buffering effect appears to be less for prolonged high rainfall (Birkinshaw et al. 2014). While water tables typically fall, the contribution of forests to flood mitigation is difficult to predict as it is determined by many factors, including the nature of the rainfall event, forest type and age, forest design and management, soil type, ground cover, establishment drains and subsequent natural infilling of these drains (Nisbet and Thomas 2006, Robinson et al. 2003, Crockford and Richardson 2000, Teklehaimanot and Jarvis 1991). As felling inevitably removes some of the benefits, Nisbet and Thomas believe that semi-natural forests can offer greater scope for flood mitigation, but note that broadleaf woodland involves lower water uptake.

Cost-based valuation methods can be used to indicate the potential damage cost averted due to the hydrological regulating services provided by forests. Economic losses as a result of flooding have risen sharply in recent decades largely because of land use modification within river catchments (Harrigan et al. 2014, OPW 2003). For example, the 2009 floods in Cork in south-west Ireland cost the city authorities €35 million with a total cost to homes and businesses estimated at between €80 and €100 million[12]. The economic losses include transport disruption and loss of business

[12] Owens McCarthy insurance assessors as quoted in The Irish Times (18/7/02).

(Merz et al. 2010) as well as social impacts such as temporary relocation, stress and anxiety (Otto et al. 2006, Wolf et al. 2006). However, the spatial distribution of forests in Ireland means that any mitigation of flooding is likely to impact most on agricultural land. In the UK, flood damage to grazing land has been estimated at between €100 and €750 ha^{-1} per event depending on the season and intensity of the flooding (Posthumus et al. 2009). More significant avoided costs would be realised where there are settlements downstream of forests. This ES benefit could also be increased through the targeting of future forest planting.

While there is evidence to support the flood mitigation potential of forests, many plantations have been planted on peat-based or wet mineral soils of low permeability. Management practices may also exacerbate rather than alleviate flooding. The presence of drainage ditches for forestry planted on peat soils in the Coalburn catchment in Wales was found to result in an immediate 15% increase in peak flows (Birkinshaw et al. 2014). However, streamflow in the catchment fell below that associated with the original vegetation as the trees matured, by which stage reductions in peak flow in the region of 10-20% were recorded (Robinson et al. 2003). In Ireland, discharge during rainfall events from a high gradient peaty catchment with mature conifer forest was found to be significantly higher than in a comparable moorland system (Kelly-Quinn et al. 1996).

Overall, the ES value of forests in Ireland in moderating run off depends on where the trees are planted, including soil type, drainage network and the susceptibility of downstream infrastructure to flooding. The current benefits may be modest, but this does not preclude the potential benefit of targeting planting to mitigate flood risk.

<u>Water quality and aquatic ecology</u>

The presence of natural riparian woodland provides a further regulating ES as it reduces bankside erosion and contributes to the removal of pollutants and contaminants from surface run-off (Calder 2007, Dudley and Stolton 2003). This reduces the pressures placed on the aquatic ecosystem which itself has a remarkable capacity to assimilate organic matter and nutrients (Lewandowski et al. 2011, Gray 2004).

Riverside trees have a direct positive impact on stream temperature which has been shown to influence multiple aspects of stream ecology (Poole and Berman 2001, Beschta et al. 1987, Larson and Larson 1996, Wilkerson et al. 2006, Webb and Crisp 2006). In their absence, acute temperature stress can impact on the development and survival of juvenile salmonids (Elliott and Elliott 1995, Armstrong et al. 2003, Rimmer et al. 1985). Conversely, too much shade can reduce the abundance and productivity of macro-invertebrates (Behmer and Hawkins 1986). Consequently, discontinuous riparian cover is ideal. Riparian woodland also supplies aquatic fauna with nutrients from woody debris and leaf fall (Lehane et al. 2002) and provides a variety of terrestrial invertebrates for fish (Ryan and Kelly-Quinn 2015). It is also a habitat for aquatic insects which further improve water quality by grazing algal growth (Sturt et al. 2013).

The bulk of these ES are provided by broadleaf riparian vegetation such as riverside willow or alder rather than by forests. Riparian vegetation is, for example, useful for intercepting nutrient pollution from agricultural run-off or domestic septic tanks (Howley et al. 2014, Lowrance et al. 1997). At the national level, the proportion of general forest cover in Irish catchments also tends to be associated with better water quality (Howley et al. 2014, Donohue et al. 2005). Older coniferous plantings often introduced excess riverside shade, but current regulations require that a buffer strip is provided between rivers and commercial conifer species and there is an opportunity for native riparian species to colonise this space or to be planted (see McConigley et al. 2015).

In economic terms, these ES reduce the cost of measures needed to meet Ireland's obligations under the EU Water Framework Directive (WFD). Vegetated buffer strips, including riparian woodland, can also provide a barrier against pathogens or organic pollutants that contribute to health risks such as water-borne gastroenteritis, cryptosporidium and carcinogenic trihalomethanes (Artwill et al. 2002). To achieve the WFD requirement of "good status" for all surface waters, EU Member States have had to make substantial investments in water and wastewater treatment and catchment management. Ultimately, these measures rely on public support. Value transfer studies indicate that the public is willing to pay on average €32 and €66 per household per year for respectively small and large improvements in water quality (Norton et al. 2012)[13]. In a primary valuation study of the River Boyne by Stithou et al. (2011), conditions supporting aquatic biodiversity were identified as important elements of economic welfare along with health and visual criteria. Angling values are also relevant given the contribution of riparian woodland to salmonids. On average, each rod-caught salmon in Ireland has been valued at €1,000 as well as being a significant driver of the tourism economy (Indecon 2003).

Potential adverse impacts on water quality and aquatic ecosystem services

From the opposite perspective, there are also potentially adverse effects from forestry on water quality, and particularly from plantation forestry, although these ecosystem disservices can be addressed through appropriate management. Problems can arise from eutrophication (Drinan et al. 2013, Thimonier et al. 1994, Machava et al. 2007), sedimentation (Madej 2001, Kreutzweiser and Capell 2001) and freshwater acidification (Kelly-Quinn et al. 1996, Giller and O'Halloran 2004) at various stages in the forest cycle. Of these, most eutrophication affects 38% of surface waters in

[13] Transfer of willingness-to-pay values from overseas adjusted for the characteristics of the Irish population and rivers.

Ireland but is due mainly to poor agricultural practice rather than forests (McGarrigle et al. 2010). Nitrate losses from planted forests in Ireland are low (McGarrigle et al. 2010, Silgram et al. 2008) and much phosphorus is retained by the trees or intercepted by undergrowth (Jennings et al. 2003, Reynolds and Davies 2001). An exception occurs on peat soils which can leach phosphorus readily (Finnegan et al. 2014, Kelly-Quinn et al. 2016). Forest induced eutrophication is a major threat to peatland lakes and rivers due to their inherent oligotrophic status (Ryder et al. 2014, Drinan et al. 2013, Renou-Wilson et al. 2008).

Forests have been linked to the mobilisation of sediment particularly during site preparation and harvesting (Moffat 1988, Giller and O'Halloran 2004). Excess sedimentation in water courses clouds the water and inhibits photosynthesis by macrophytes which perform an important oxygenating service (Gallagher et al. 2001, Wood and Armitage 1997, Madsen et al. 2001). Sediment from various sources can smother gravel beds and impact adversely on the habitat for invertebrates and salmonids (Wood and Armitage 1997, Johnson et al. 2000). A particular concern is the freshwater pearl mussel (*Margaritifera margaritifera* L.) whose population has fallen dramatically (Geist 2005, Geist 2010). Excess sediment is detrimental to the early post settlement stage as it clogs the animal's gills (Moorkens 2010).

Mature plantations in-situ have lower rates of sediment loss than those recorded from agriculturally dominated catchments (Reubens et al. 2007, Montgomery 2007). However, forest roads and harvesting can release large volumes of sediment (Quinn and Stroud 2002, Grace 2005, Perry et al. 1999). Harvesting and replanting protocols, including use of buffer zones and sediment traps, can intercept run-off and sediment (Silgram et al. 2008, Bastrup-Birk and Gundersen 1999, Rodgers et al. 2012). This advice is now included in Irish Forest Service guidelines, reducing the potential impact on fish and other freshwater biodiversity.

Of the third environmental effect, acidification occurs when trees scavenge nitrogen and sulphur compounds from the atmosphere and release these into water bodies following rainfall (Fowler et al. 1989, Ormerod et al. 1991, Jenkins et al. 1990). Acidification can also arise from release of organic acids from peaty soils, now a key driver of acidification in Irish conifer forests (Feeley et al. 2014). It can impact on plants and invertebrates (Mulholland et al. 1986, Vinebrooke and Graham 1997, Guerold et al. 2000, Dangles et al. 2004) and impair the development of salmon eggs and smolts (Gensemer and Playle 1999, McCormick et al. 2009, Harrison et al. 2014). Whereas high densities of aquatic invertebrates have been associated with deciduous woodland whose leaf litter is rapidly broken down (Richardson et al. 2004), dense conifer plantations do present a risk due to the permanence of needles. In Ireland, the prevalence of Atlantic weather systems and predominance of limestone bedrock does reduce the risk from acidification (Kaste and Skjelkvåle 2002) compared with some other countries. However, while the atmospheric driver has reduced over time, high DOC concentrations due to forestry planted on peat soils are a source of acidification on base-poor geology (Feeley et al. 2013).

Habitat services

Habitat or supporting services were listed by the MEA, but to avoid double-counting the CICES classification treats these as ecological processes or functions that contribute to final ES. Four Irish forest habitats are listed as priority habitats in Annex 1 of the EU Habitats Directive; old sessile oak woods (91A0), alluvial forests (91E0), yew woodlands (91JO) and bog woodland (91DO). These habitats are valued for the species they support, but also, in their own right, as relatively rare examples of semi-natural woodland. Other forest types provide an important habitat service for both threatened and familiar wildlife species (Irwin et al. 2013). Active management for biodiversity is required on 15% of the forest area of all new grant-aided forest plantings, including private plantings (Forest Service 2000).

Linking final ES values back to biophysical conditions is extremely difficult. Economic valuation has been used in Ireland to demonstrate species or habitat values of introducing more tree species (Mill et al. 2007), nature reserves (Scarpa et al. 2000) and biodiversity areas (Upton et al. 2012). A strong relationship is evident between these stated values and respondents' access to forests (Upton et al. 2014). However, there is often a lack of information with which to link flows of final ES of social and economic value to the underpinning biological processes (Durance et al. 2016). It is believed that a diverse range of species, or specifically functional diversity, supports ecosystem resilience to change or external shocks and its capacity to support essential ES (Perrings et al. 2010, Durance et al. 2016). Typically, such a diverse range of specialist species is found in native and semi-natural woodland rather than plantation forest, which is usually characterised by a rather small number of tree types (Coote et al. 2012, Irwin et al. 2013, Sweeney et al. 2010, Gamfeldt et al. 2013). Due to its geographical separation from mainland Europe, combined with the fragmented nature of remaining semi-natural woodland, Ireland has retained only a small subset of the specialist woodland species found in Britain and other parts of the continent (Kelly 2008). The remaining area of native species woodland provides continuity of habitat for some species, although many woodlands are in poor condition due to lack of management, deer browsing and invasive non-native plant species, in particular rhododendron (Bullock et al. 2014).

Nevertheless, in many parts of the world, plantation forest can provide surrogate habitat for forest wildlife. Indeed, recent research in Ireland has demonstrated that conifer plantations can harbour a range of plant and animal biodiversity, including protected native species (Irwin et al. 2013). The net value of this planting depends on where it occurs and what it replaces. As native woodland is protected, much plantation forest has replaced open habitats on peatland soils and wet upland grazing land (Smith et al. 2006). Forest Service rules have reduced the recent level of planting on the former, but wet grassland is of habitat value if low intensity grazing is maintained (Wilson et al. 2012),

Although 23% of planting between 2002 and 2010 has involved broadleaf species, this proportion has been increasing. This trend reflects current grant support and biodiversity guidelines that stipulate that 10% of the planted area should comprise of broadleaf species and that further areas are set aside specifically for biodiversity enhancement. Potentially, new afforestation could be targeted to maximise biodiversity, particularly in relation to the siting of new forests in the landscape to complement the existing mosaic of habitats or to provide connectivity with existing woodland[14].

Cultural services

Natural ecosystems provide the setting for a variety of human interactions with the outdoor environment (Church et al. 2011). According to the MEA (2005), cultural ES can encompass aesthetic, spiritual, health and social benefits and associations as well as more direct physical interaction. Recreation and amenity benefits are among the most important cultural services provided by Ireland's forests, but a quantification of the extent of these benefits is compounded by the lack of reliable figures on visitation. Coillte refers to a figure of 18 million visits for its own forest estate based on the median number of trips reported from in-forest interviews conducted by Fitzpatrick Associates (2005). The household survey that supplemented these interviews indicated a higher total of 38 million visits per year to all forest areas in Ireland. Although considerably more than earlier estimates, a high figure is possible given repeat visits, noting also the evidence of visits to local authority owned forest located close to urban centres. Upton et al. (2014) have estimated forest visitation at 29 million by combining survey data collected on behalf of COFORD (Irish Council for Forest Research and Development) with spatially explicit forest recreational demand estimates for a simulated population of Ireland (SMILE model). A travel cost estimate based on these figures indicates an average travel cost of €6.16 per visit. This compares with an average of stated preference values of €5 per visit for seven of the main surveys undertaken to date[15]. On this basis, the direct recreational value alone would be worth €179 million per year.

As well as utility benefits, forest visits provide indirect ES benefits through their contribution to physical and mental health. Physical exercise is vital in combating obesity, cardio-vascular and musculo-skeletal diseases, stroke and cancer. If applied to Ireland, figures for the UK (CJC Consulting 2005) suggest that just a 1% reduction

[14] See Peterken (2002) for more discussion of spatial afforestation benefits.

[15] i.e. Ní Dhubháin (1994), Clinch (1999), Fitzpatrick Associates (2005a), Fitzpatrick Associates (2005b), Hynes et al. (2007a), Hynes et al. (2007b) and Cullinan (2011).

in the 24% of the population who are physically inactive would reduce premature deaths and morbidity amongst people under 75 years by 715 cases per year and save €37 million in annual healthcare costs and productivity losses. If the Health Economic Assessment Tool (HEAT) (www.heatwalkingcycling.org) developed for the World Health Organisation is applied to just the 8% of respondents to the Coillte survey who visit forests at least once per month and are engaged in active exercise (mostly walking), this would suggest savings on premature mortality of at least €113 million per year and potentially as much as €259 million per year[16]. While the direct and indirect value of forest recreation is substantial, it is notoriously difficult to attribute health benefits to any one activity (Sunderland 2012). In addition, recreation and health benefits do not necessarily imply a strong relationship with the forest ecosystems. For example, Coillte has installed several popular mountain bike trails in recent years, but this activity could be argued to involve only a partial relationship with forests as facilities could be provided in other environments. However, as Ireland is poorly supplied with walking opportunities relative to many other European countries given the absence of laws permitting access to private land (Buckley et al. 2009), this lack of provision means that publicly-owned forest can make a distinct contribution given that it is amongst the few rural environments where people can walk.

There are other activities such as nature viewing or birdwatching that do have a strong relationship with forests. These interests are relevant to non-use values too. Nature – or naturalness – makes a significant contribution to casual visits and cultural services as noted earlier (Termansen et al. 2013, Edwards et al. 2012). In Ireland, a stated preference survey by Upton et al. (2012) found that people were willing to pay €21 per year for "biodiversity enhancement areas" totalling 15% of a forest's area and would pay €33 per year for an increase in this area from 0% to 30%, in addition to higher sums for broadleaf or mixed species forest compared with conifers. Nature has also been identified as inducing psychological improvements in mood, concentration and attention (Ulrich 1981), reduced mental fatigue (Kuo 2001) and reductions in stress-related diseases (Hartig et al. 1991). A variety of studies have demonstrated the benefits that walking in natural environments can have by increasing positive mood, concentration and mental performance in cognitive tests (Townsend 2006, Berman et al. 2008). Effects have been detected for elderly people (De Vries et al. 2003, Ottosson and Grahn, 2005), children with Attention Deficit Disorder (ADD) (Kuo and Taylor 2004) and people with major depressive disorder (MDD) (Berman et al. 2012).

In a survey of visitors to two Irish forests, Iwata et al. (2016; this issue) found that the main psychological well-being benefit experienced by forest visitors was mental

[16] Range is based on 30 and 60 minutes exercise and assumes an equal share of weekly and daily visits for the 41% of adult population engaged in active exercise. The model only allows for daily and weekly exercise. As daily exercise accounts for over 70% of the estimated benefits, the most accurate figure is likely to be between these ranges. The tool estimates the value of a statistical life at €2,587,175.

relaxation. Mental relaxation can be considered synonymous with psychological restoration, a recognized benefit of spending time in the natural environment which has been described as a product of emotional interaction with the natural environment (Ulrich 1983). Iwata et al. evaluated a pilot programme of forest walks organised for people suffering from depression and found that those participants registered improvements immediately following the visits. They also realised a significant reduction in depression symptoms following therapy in which these visits were an important element. Social interaction, being outdoors, and physical exercise were described as key factors. However, similar problems of attribution apply to mental health benefits as to physical exercise. It is acknowledged that the specific role of forest visits would be extremely difficult to identify given the complementary treatment provided and the complex nature of mental health.

Discussion

Forestry in Ireland provides many of the same ES as other countries located in similar climate zones and with a similar forest composition. These ES have both an economic and a socio-cultural value, although it would be unreliable to aggregate benefits estimates for an average forest due to the varying degree to which these values depend on the commercial or non-commercial nature of the forest, its species composition, age, location and management.

Forestry provides a valuable provisioning service in the form of timber and wood products. Conifer species grow well in the Irish climate and have enabled the country to build up a prosperous forestry sector. Although the timber may be considered lower quality than native hardwoods in terms of strength or grain, it nevertheless has a sizeable market particularly for construction purposes. There are related regulating service benefits in that these are relatively long-term uses by which the carbon content remains locked away for many decades. The market for forest products also provides the rationale for planting and the young age of much of Ireland's forest means that there is a high level of sequestration during the trees' growth. Losses of soil carbon occur at various times in the forest cycle, but can be mitigated to allow the carbon sequestration by forests to exceed that of other land uses. Recent growth in the market for fuelwood has also provided an expanded outlet for thinnings and residue which can substitute for non-renewable carbon fuels.

Other important regulating ES include water flow moderation and benefits for water quality. The benefits should be viewed objectively. The capacity to moderate run-off may diminish for more severe rainfall events and is less likely to be realised in economic terms in remote rural areas than in the vicinity of urban areas where valuable real estate is at risk. Likewise, the benefits to water quality are supplied more by alluvial woodland than by conifer forest in general. Forest, especially mature broadleaf or mixed species forest, also provides habitats for biodiversity, supporting regulating, provisioning and cultural ES.

Many cultural ES benefits relate to a range of opportunities that forests provide for amenity, although some of these activities are not specific to this environment, but are often due to the accessibility of forests relative to areas of other land use. Nevertheless, these benefits are enhanced by the visual setting and the biodiversity that forests support. They are borne out by stated preference surveys and by the external benefits for local economies from recreation and tourism. Although it is difficult to attribute and quantify the benefits to health, studies of both physical and mental health referenced in this paper, indicate the rounded contribution that forests make to well-being.

For all these services appropriate management is essential. The Forest Service's mix of regulation and incentives has contributed to timber and carbon sequestration by increasing the proportion of broadleaf planting, both to provide a sustainable supply of hardwoods for a diverse wood processing sector and for long term carbon storage in-situ by amenity plantings. Existing regulations also reduce the risk of soil disturbance and minimise the use of fertilisers or pesticides that present a risk to aquatic water quality. There are particular benefits in using buffer strips comprised of open areas and native riparian species to protect against nutrient and sediment run-off. There are also opportunities to provide a diversity of forest habitat and biodiversity. A continuous supply of ES benefits is supported by premium payments, but could be strengthened through a renewed supply of incentives for proactive habitat management, invasive plant control and deer management.

Many of these benefits are complementary to one another and can ensure that existing plans for forest expansion simultaneously meet Ireland's international and European policy obligations with regard to climate change, water quality, biodiversity and landscape. For example, protecting river quality attracts biodiversity as well as active and passive recreation benefits. Planting broadleaves, including native species, provides habitat for biodiversity, but also settings for amenity use. There are economic benefits such as employment and business opportunities for local communities and socio-cultural benefits such as security of homes and livelihoods, well-being and health. The complementary nature of these ES leads naturally to an argument for targeting incentives to where the benefits are highest or most effectively achieved. For example, targeted and cooperative initiatives between neighbouring landowners can be used to extend planting beside vulnerable stretches of river to protect water quality; to connect isolated areas of forest including remaining native woodland; or to plant and link woodlands close to where people live or are under-provided with forest.

Conclusion

This paper has set out to provide an objective assessment of the level of ES provided by forests in Ireland, including evidence of the scale of the economic and social benefits. When planted in suitable locations, on suitable soils, forests can provide a wide range of valuable ES. Negative impacts can occur when these conditions do not apply. Regulations and incentives can be used to ensure that planting take places in appropriate areas and with subsequent management minimises the risk of adverse outcomes.

Forests, including plantation forests, can be managed to supply many important benefits covering the full range of intermediate and final ES. These include timber supply, carbon sequestration, moderation of run-off, protection of water quality, amenity, recreation and health. These types of ES, and the means to maximise their flow, are relevant to other countries with a similar forest structure. This review has sought to provide a comprehensive overview, but also to demonstrate the interactions that exist between ecological processes, functions and services that could be overlooked by singular disciplinary perspectives. Ireland's forest policy accepts the need to recognise the role of ES benefits. If linked to management incentives and targeted planting, this will contribute to our international policy obligations with regard to climate change, water quality, biodiversity and landscape.

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References

Allen, A. and Chapman, D. 2001. Impacts of afforestation on groundwater resources and quality. *Hydrogeology Journal* 9: 390–400.

Armstrong, J., Kemp, P., Kennedy, G., Ladle, M. and Milner, N. 2003. Habitat requirements of Atlantic salmon and brown trout in rivers and streams. *Fisheries Research* 62: 143–170.

Artwill, E.R., Hou, L., Karle, B.M., Hartenr, T., Tate, K.W. and Dahlgren, R.A. 2002. Transport of *Crytosporidium parvum* oocysts through vegetated buffer strips and estimated filtration capacity. *Applied Environmental Microbiology* 68: 5517–5527.

Bastrup-Birk, A. and Gundersen, P. 1999. Water quality improvements from afforestation in an agricultural catchment in Denmark illustrated with the INCA model. *Hydrology and Earth System Sciences* 8: 764–777.

Bastrup-Birk, A. and Marchetti, M. 2011. *Maintenance and Encouragement of Productive Functions of Forests (Wood and non-Wood)*. State and trends in sustainable forest management in Europe. Food and Agriculture Organization of the United Nations, FAO, p. 51–63.

Behmer, D.J. and Hawkins, C.P. 1986. Effects of overhead canopy on macroinvertebrate production in a Utah stream. *Freshwater Biology* 16: 287–300.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. and Courchamp, F. 2012. Impacts of climate change on the future of biodiversity. *Ecology letters* 15: 365–377.

Berman, M.G., Jonides, J. and Kaplan, S. 2008. The cognitive benefits of interacting with nature. *Psychological Science* 19: 1207–1212.

Berman, M.G., Kross, E., Krpan, K.M., Askren, M.K., Burson, A. and Deldin, P.J. 2012. Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders* 140: 300–305.

Beschta, R.L., Bilby, R.E., Brown, G.W., Holtby, L.B. and Hofstra, T.D. 1987. Stream temperature and aquatic habitat: fisheries and forestry interactions. *Streamside management: Forestry and Fishery Interactions* 57: 191–232.

Birkinshaw, S.J., Bathurst, J.C. and Robinson, M. 2014. 45 years of non-stationary hydrology over a forest plantation growth cycle, Coalburn catchment, Northern England. *Journal of Hydrology* 519: 559–573.

Black, K. and Farrell, E. 2006. *Carbon Sequestration and Irish Forest Ecosystems*. COFORD, National Council for Forest Research and Development, Dublin.

Bolund, P. and Hunhammer, S. 1999. Ecosystem services in urban areas. *Ecological Economics* 29: 293–301.

Bradshaw, C.J., Sodhi, N.S., Peh, K.S.H. and Brook, B.W. 2007. Global evidence that deforestation amplifies flood risk and severity in the developing world. *Global Change Biology* 13: 2379–2395.

Buckley, C., Hynes, S., van Rensburg, T.M. and Doherty, E. 2009. Walking in the Irish countryside: landowner preferences and attitudes to improved public access provision. *Journal of Environmental Planning and Management* 52: 1053–1070.

Bullock, C. and Hawe, J. 2013. The Natural Capital Value of Native Woodland in Ireland. Woodlands of Ireland.

Bullock, C., Hawe, J. and Little, D. 2014. Realising the ecosystem service value of native woodland in Ireland. *New Zealand Journal of Forestry Science* 44: (Suppl 1).

Byrne, K.A. 2010. The role of plantation forestry in Ireland in the mitigation of greenhouse gas emissions. *Irish Forestry* 67: 86–96.

Calder, I.R. 2007. Forests and water – ensuring forest benefits outweigh water costs. *Forest Ecology and Management* 251: 110–120.

Calder, I.R., Reid, C.T., Nisbet, T.R., Armstrong, L.K., Green, J.C. and Parkin, G. 2002. Impact of lowland forests in England of the potential impact on water resources of afforestation. Department of the Environment, Food and Rural Affairs. London.

Chen, J., Ustin, S.L., Suchanek, T.H., Bond, B.J., Brosofske, K.D. and Falk, M. 2004. Net ecosystem exchanges of carbon, water, and energy in young and old-growth Douglas-fir forests. *Ecosystems* 7: 534–544.

Church, A., Burgess, J. and Ravonscroft, N. 2011. Cultural ecosystem services. In *UK National Ecosystem Assessment (UK NEA)*.

CICES. 2013. Common International Classification of Ecosystem Services. Prepared by the University of Nottingham and Centre for Environmental Management for European Environment Agency.

CJC Consulting. 2005. Economic Benefits of Accessible Green Spaces for Physical and Mental Health. *CJC Consulting with Prof. Ken Willis and Dr. Liesl Osman*. Final report for the UK Forestry Commission. Edinburgh.

Clinch, J.P. 1999. *Economics of Irish Forestry: Evaluating the Returns to Economy and Society*. COFORD: Dublin, pp. 276.

Collier, P., Short, I. and Dorgan, J. 2004. *Markets for Non-Wood Forest Products*. COFORD, National Council for Forest Research and Development. Dublin.

Coote, L., French, L., Moore, K., Mitchell, F. and Kelly, D. 2012. Can plantation forests support plant species and communities of semi-natural woodland? *Forest Ecology and Management* 283: 86–95.

Crockford, R.H. and Richardson, D.P. 2000. Partitioning of rainfall into throughfall, stemflow and interception: effect of forest type, ground cover and climate. *Hydrological Processes* 14: 2903–2920.

DAFM. 2014. *Forests, Products And People: Ireland's Forest Policy – A Renewed Vision*. Department of Agriculture, Food and the Marine. Dublin.

Dangles, O., Gessner, M.O., Guerold, F. and Chauvet, E. 2004. Impacts of stream acidification on litter breakdown: implications for assessing ecosystem functioning. *Journal of Applied Ecology* 41: 365–378.

De Vries, S., Verheij, R.A., Groenewegen, P.P. and Spreeuwenberg, 0. 2003. Natural environments –healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environment and Planning* 35: 1717–1731.

Donlan, J., Skog, K.E. and Byrne, K.A. 2012. Carbon storage in harvested wood products for Ireland 1961–2009. *Biomass and Bioenergy* 46: 731–738.

Donohue, I., McGarrigle, M.L. and Mills, P. 2005. Linking catchment status and water chemistry with the ecological status of Irish rivers. *Water Research* 40: 91–98.

Drinan, T., Graham, C., O'Halloran, J. and Harrison, S. 2013. The impact of catchment conifer plantation forestry on the hydrochemistry of peatland lakes. *Science of the Total Environment* 443: 608–620.

Drinan, T., Graham, C., O'Halloran, J. and Harrison, S. 2013. The impact of conifer plantation forestry on the Chydoridae (Cladocera) communities of peatland lakes. *Hydrobiologia* 700: 203–219.

Dudley, N. and Stolton, S. 2003. Running pure: the importance of protected forest areas to drinking water. *The Arguments for Protection Series*. World Bank. WWF Alliance for Forest Protection and Sustainable Use.

Durance, I., Bruford, M.W. and Chalmers, R.E.A. 2016. The challenges of linking ecosystem services to biodiversity: lessons from a large-scale freshwater study. *Advances in Ecological Research* 54: 87–134.

Edwards, D.M., Jay, M. Jensen, F.S. Lucas, B. Marzano, M. Montagné, C. Peace, A. and Weiss, G. 2012. Public preferences across Europe for different forest stand types as sites for recreation. Ecology and Society 17: 27–38.

Elliott, J. and Elliott, J. 1995. The effect of the rate of temperature increase on the critical thermal maximum for parr of Atlantic salmon and brown trout. *Journal of Fish Biology* 47: 917–919.

EU. 2011. *The EU Biodiversity Strategy to 2020*. European Union. Luxembourg.

FAO. 2005. *Forests And Floods: Drowning in Fiction or Thriving on Facts*. FAO and CIFOR. Bangkok, Thailand.

FAO. 2010. *Planted Forests in Sustainable Forest Management – a Statement of Principles*. FAO Organisation, Rome.

Farley, K.A., Jobbágy, E.G. and Jackson, R.B. 2005. Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology* 11: 1565–1576.

Feeley, H.B., Bruen, M., Blacklocke, S. and Kelly-Quinn, M. 2013. A regional examination of episodic acidification response to reduced acidic deposition and the influence of plantation forests in Irish headwater streams. *Science of the Total Environment* 443: 173–183.

Finnegan, J., Regan, J.T., Fenton, O., Lanigan, G.J., Brennan, R.B. and Healy, M.G. 2014. The short term effects of management changes on watertable position and nutrients in shallow groundwater in a harvested peatland forest. *Journal of Environmental Management* 142: 46–52.

Fisher, B., Turner, K. and Morling, R. 2009. Defining and classifying ecosystem services for decision making. *Ecological Economics* 68: 643–653.

Fitzpatrick Associates. 2005. *Economic Value of Trails and Forest Recreation in the Republic of Ireland*. Dublin.

Forest Europe. 2014. Expert Group and Workshop on Valuation of Forest Ecosystem Services. Ministerial Conferences on the Protection of Forests in Europe. Madrid.

Forest Service. 2013. *National Forest Inventory – Republic of Ireland –Results*. Forest Service, Department of Agriculture, Food and the Marine. Wexford, Ireland.

Forest Service. 2000. *Forest Biodiversity Guidelines*. Dublin, pp. 10.

Fowler, D., Cape, J., Unsworth, M., Mayer, H., Crowther, J., Jarvis, P.G., Gardiner B. and Shuttleworth, W.J. 1989. Deposition of atmospheric pollutants on forests. *Philosophical Transactions of the Royal Society of London B, Biological Sciences* 324: 247–265.

Gallagher, M., Johnson, M., O'Gorman, K., O'Halloran, J., Giller, P. and Clenaghan, C. 2001. The impact of clearfelling operations on physico-chemical parameters of aquatic ecosystems in southwest Ireland. *Internationale Vereinigung fur Theoretische und Angewandte Limnologie Verhandlungen* 27: 1108–1115.

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M.C., Fröberg, M., Stendahl, J., Philipson, C.D., Mikusiński, G., Andersson, E., Westerlund, B., Andrén, H., Moberg, F., Moen, J. and Bengtsson, J. 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. *Nature Communications* 4: 1340–1348.

Geist, J. 2005 Conservation genetics and ecology of European freshwater pearl mussels *(Margaritifera margaritifera* L.*)*, PhD Thesis, Technischen Universität Müchen.

Geist, J. 2010 Strategies for the conservation of endangered freshwater pearl mussels (Margaritifera margaritifera L.): a synthesis of conservation genetics and ecology. *Hydrobiologia* 644: 69–88.

Gensemer, R.W. and Playle, R.C. 1999. The bioavailability and toxicity of aluminum in aquatic environments. *Critical Reviews in Environmental Science and Technology* 29: 315–450.

Giller, P.S. and O'Halloran, J. 2004. Forestry and the aquatic environment. Studies in the Irish context. *Hydrology and Earth System Sciences Discussions* 8: 314–326.

Giller, P.S. and O'Halloran, J. 2004. Forestry and the aquatic environment: studies in an Irish context. *Hydrology and Earth System Sciences Discussions* 8: 314–326.

Gobin, A., Campling, P., Janssen, L., Desmet, N., van Delden, H., Hurkens, J., Lavelle, P. and Berman, S. 2011. *Soil Organic Matter Management across the EU – Best Practices, Constraints and Trade-offs*. European Commission, DG Environment.

Gomez-Baggethun, E. and Barton, D.N. 2012. Classifying and valuing ecosystem services for urban planning. *Ecological Economics* 86: 235–246.

Grace, J. 2005. Forest operations and water quality in the South. *Transactions of the ASAE* 48: 871–880.

Gray, N. 2004 *Biology of Wastewater Treatment*. 2nd ed. Imperial College Press.

Guerold, F., Boudot, J.P., Jacquemin, G., Vein, D., Merlet, D. and Rouiller, J. 2000. Macroinvertebrate community loss as a result of headwater stream acidification in the Vosges Mountains (NE France). *Biodiversity and Conservation* 9: 767–783.

Guitart, A.B. and Rodriguez, L. 2010. Private valuation of carbon sequestration in forest plantations. *Ecological economics* 69: 451–458.

Haines-Young, R. and Potschin, M. 2010. The links between biodiversity, ecosystem services and human well-being In *Ecosystem Ecology: A New Synthesis*. Eds. Raffaelli, D. and Frid, C., Cambridge University Press, pp. 110–139.

Hargreaves, K.J., Milne, R. and Cannell, M.G.R. 2003. Carbon balance of afforested peatland in Scotland. *Forestry* 76: 299–317.

Harrigan, S., Murphy, C., Hall, J., Wilby, R.L. and Sweeney, J. 2014. Attribution of detected changes in streamflow using multiple working hypotheses. *Hydrology and Earth System Sciences* 18: 1935–1952.

Harrington, T. and Cullen, M. 2008. Assessment of wild edible fungi production in Irish woodlands. COFORD.

Harrison, S.C., Hutton, S., Jan-Robert, B., Cruickshanks, R.H., Johnson, J., Guillaume, J., Tadeuz, K., Matson, R., O'Halloran, J., Phelan, P. and Kelly-Quinn, M. 2014. Contrasting impacts of conifer forests on brown trout and Atlantic salmon in headwater streams in Ireland. *Biology and Environment* 114B 219–231.

Hartig, T., Mang, M. and Evans, G.W. 1991. Restorative effects of natural environment experiences. *Environment and Behaviour* 23: 3–26.

Howley, P., Buckley, C., Jordan, R., O'Donoghue, C., Hynes, S. and Green, S. 2014. A spatial analysis of the distribution of river water quality benefits and the major forces affecting river water quality across the Republic of Ireland. *EPA Strive Report*. Environmental Protection Agency. Johnstown Castle, Wexford.

Howley, P., Ryan, M. and Donoghue, C.O. 2011. Forestry in Ireland: An examination of individuals' preferences and attitudes for the non-market benefits of forests. *Irish Geography* 44: 291–302.

Indecon. 2003. An economic/socio-economic evaluation of wild salmon in Ireland. Indecon International Economic Consultants for Central Fisheries Board.

Irwin, S., Kelly, D.L., Kelly, T.C., Mitchell, F.J.G., Coote, L., Oxborough, A., Wilson, M.W., Martin, R.D., Moore, K.A., Sweeney, O., Dietzsch, A. and O'Halloran, J. 2013. Do Irish forests provide habitat for species of conservation concern? *Biology and Environment, Proceedings of the Royal Irish Academy*. 113: 273–279.

Irwin, S., Pedley, S.M., Coote, L., Dietzsch, A.C., Wilson, M.W., Oxborough, A., Sweeney, O., Moore, K.M., Martin, R., Kelly, D.L., Mitchell, F.J.G., Kelly, T.C. and O'Halloran, J. 2013.The value of plantation forests for plant, invertebrate and bird diversity and the potential for cross taxon surrogacy. *Biodiversity and Conservation* 23: 697–714.

Iwata, Y., Ní Dhubháin, Á. and Bullock, C.H. 2016. The psychological and physical impacts of spending time in forests: A case study of two forests in Ireland. *Irish Forestry* 73: 180–199 (this issue).

Jenkins, A., Cosby, B., Ferrier, R., Walker, T. and Miller, J. 1990. Modelling stream acidification in afforested catchments: an assessment of the relative effects of acid deposition and afforestation. *Journal of Hydrology* 120: 163–181.

Jennings, E., Mills, P., Jordan, P., Jensen, J.P., Søndergaard, M., Barr, A., Glasgow, G. and Irvine, K. 2003. Eutrophication from agricultural sources: seasonal patterns & effects of phosphorus – Final Report. Environmental Protection Agency, Ireland.

Johnson, M.J., O'Gorman, K., Gallagher, M., Clenaghan, C., Giller, P.S. and O'Halloran, J. 2000. The identification and amelioration of the impacts of clearfelling operations on macroinvertebrates and salmonids in Ireland. *Verhandlungen des Internationalen Verein Limnologie* 27: 1565–1570.

Kaste, Ø. and Skjelkvåle, B.L. 2002 .Nitrogen dynamics in runoff from two small heathland catchments representing opposite extremes with respect to climate and N deposition in Norway. *Hydrology and Earth System Sciences Discussions* 6: 351–362.

Kelly, T.C. 2008. The origin of the avifauna of Ireland. *The Irish Naturalist*,29 (Special Supplement: Mind the gap. Postglacial colonization of Ireland pp. 97–107.

Kelly-Quinn, M., Tierney, D., Coyle, C. and Bracken, J.J. 1996. Factors affecting the susceptibility of Irish soft-water streams to forest-mediated acidification. *Fisheries Management and Ecology* 3: 287–301.

Kelly-Quinn, M., Bruen, M., Harrison, S., Healy, M., Clarke, J., Drinan, T., Feeley, H.B., Finnegan, J., Graham, C., Regan, J. and Blacklocke, S. 2016. Assessment of the impacts of forest operations on the ecological quality of water (HYDROFOR). EPA Synthesis Report (2007-WQ-CD-2-S1). Environmental Protection Agency, Johnstown Castle, Co. Wexford, Ireland. Available at: http://erc.epa.ie/safer/reports [Retrieved October 2015].

Knaggs, G. and O'Driscoll, E. 2013. Woodflow and forest-based biomass energy use on the island of Ireland. Coford, Dublin.

Knaggs, G. and O'Driscoll, E. 2013. Woodflow and forest-based biomass energy use on the island of Ireland. Coford, Department of Agriculture, Food and the Marine. Dublin.

Kreutzweiser, D.P. and Capell, S.S. 2001. Fine sediment deposition in streams after selective forest harvesting without riparian buffers. *Canadian Journal of Forest Research* 31: 2134–2142.

Kuo, F.E. 2001. Aggression and violence in the inner city: Effects of environment via mental fatigue. *Environment and Behavior* 33: 543–571.

Kuo, F.E. and Taylor, A.F. 2004. A potential natural treatment for attentiondeficit/ hyperactivity disorder: evidence from a national study. *American Journal of Public Health* 94: 1580–1586.

Larson, L.L. and Larson, S.L. 1996. Riparian shade and stream temperature: a perspective. *Rangelands* pp. 149–152.

Laurance, W.F. 2007. Environmental Science: Forests and floods. *Nature* 449: 409–410.

Lehane, B., Giller, P., O'halloran, J., Smith, C. and Murphy, J. 2002. Experimental provision of large woody debris in streams as a trout management technique. *Aquatic conservation: Marine and Freshwater ecosystems* 12: 289–311.

Leonard, R.E. and Parr, S.B. 1970. Woodland trees as a sound barrier. *Journal of Forestry* 68: 282–283.

Lewandowski, J., Putschew, A., Schwesig, D., Neumann, C. and Radke, M. 2011. Fate of organic micropollutants in the hyporheic zone of a eutrophic lowland stream: Results of a preliminary field study. *Science of the Total Environment* 409: 1824–1835.

Lowrance, R., Altier, L.S., Newbold, J.D., Schnabel, R.R., Groffman, P.M., Denver, J.M., Correll, D., Gilliam, J.W., Robinson, J.L., Brinsfield, R.B., Staver, K.W., Lucas, W. and Todd, A.H. 1997. Water quality functions of riparian forest buffers in Chesapeake Bay watersheds. *Environmental Management* 21: 687–712.

Machava, J., McCabe, O., O'Dea, P., Cabral, R. and Farrell, E. 2007. Forestry Operations and Eutrophication – Penrich. *Environmental Research Technological Development and Innovation (ERTDI) Programme 2000–2006 No.78*. Environmental Protection Agency.

Madej, M.A. 2001. Erosion and sediment delivery following removal of forest roads. *Earth Surface Processes and Landforms* 26: 175–190.

Madsen, J., Chambers, P., James, W., Koch, E. and Westlake, D. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444: 71–84.

McConigley, C., Lally, H., O'Callaghan, M., O'Dea, P., Little, D., Kelly-Quinn, M. 2015. The vegetation communities of unmanaged aquatic buffer zones within conifer plantations in Ireland. *Forest Ecology and Management* 353: 59–66.

McCormick, S.D., Keyes, A., Nislow, K.H. and Monette, M.Y. 2009. Impacts of episodic acidification on in-stream survival and physiological impairment of Atlantic salmon (Salmo salar) smolts. *Canadian Journal of Fisheries and Aquatic Sciences* 66: 394–403.

McGarrigle, M., Lucey, J. and Ó Cinnéide , M. 2010. Water Quality in Ireland 2007–2009. Environmental Protection Agency, Ireland.

McGettigan, M., Duffy, P., Hyde, B., Hanley, E., O'Brien, P. 2009. Ireland National Inventory Report 2009 Greenhouse Gas Emissions 1990–2007: Reported to the United Nations Framework Convention on Climate Change. Environmental Protection Agency, Johnstown Castle Estate, Wexford, Ireland.

McKinsey. 2007. Climate change: Everyone's business—options for greenhouse gas reduction in the UK.

McKinsey. 2007. Costs and potentials of greenhouse gas abatement in Germany, *BDI initiative – Business for Climate*.

MEA. 2005. *Ecosystems and Human Well Being: Synthesis Report*. Millennium Ecosystem Assessment Washington, USA.

Merz, B., Kreibich, H., Schwarze, R. and Thieken, A. 2010. Review article" Assessment of economic flood damage". *Natural Hazards and Earth System Science* 10: 1697–1724.

Mill, G.A., Van Rensburg, T.M., Hynes, S. and Dooley, C. 2007. Preferences for multiple use forest management in Ireland: Citizen and consumer perspectives. *Ecological economics* 60: 642–653.

Millar, C.I., Stephenson, N.L. and Stephens, S.L. 2007. Climate change and forests of the future: managing in the face of uncertainty. *Ecological Applications* 17: 2145–2151.

Moffat, A. 1988. Forestry and soil erosion in Britain–a review. *Soil Use and Management* 4: 41–44.

Montgomery, D.R. 2007. Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences*. 104: 13268–13272.

Moorkens, E.A. 2010. Addressing the conservation and rehabilitation of Margaritifera margaritifera (L.) populations in the Republic of Ireland within the framework of the Habitats and Species Directive. *Journal of Conchology* 40 P. 339.

Motherway, B. and Walker, N. 2009. Ireland's Low-Carbon Opportunity: An analysis of the costs and benefits of reducing greenhouse gas emissions. Sustainable Energy Ireland.

Mulholland, P.J., Elwood, J., Palumbo, A. and Stevenson, R. 1986. Effect of stream acidification on periphyton composition, chlorophyll, and productivity. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 1846–1858.

NESC. 2012. Towards a New National Climate Policy: Interim Report of the NESC Secretariat. National Economic and Social Council.

Ní Dhubháin, Á., Bullock, C., Molooney, R. and Upton, V. 2012. An Economic Evaluation of the Market and Non-Market Functions of Forestry. Coford (Council for Forest Research and Development). Dublin.

Ní Dhubháin, Á., Gardiner, J., Davies, J., Hutchinson, W.G., Chilton, S.M., Thompson, K., Psaltopoulos, D. and Anderson, C. 1994. The socio-economic impacts of afforestation on rural development: Final Report CAMAR. European Community.

Nisbet, T.R. and Thomas, H. 2006. *The Role of Woodland in Flood Control: a Landscape Perspective*. Eds. Davies, B. and Thompson, S., pp. 118–125.

Norton, D., Hynes, S., Doherty, E., Buckley, C., Campbell, D. and Stithou, M. 2012. Benefit Transfer for Irish Water. *STRIVE Programme 2007–2013*. Environmental Protection Agency.

O'Driscoll, E. 2014. UNECE Forestry and Timber Market Report for Ireland 2013. Department of Agriculture, Food and the Marine. Dublin, P. 55.

OPW. 2003. Report of the Flood Policy Review Group. Office of Public Works, Dublin.

Ormerod, S., Rutt, G., Weatherley, N. and Wade, K. 1991. Detecting and managing the influence of forestry on river systems in Wales: results from surveys, experiments and models. *Irish Rivers: Biology and Management. Royal Irish Academy, Dublin* pp. 163–184.

Otto, K., Boos, A., Dalbert, C., Schöps, D. and Hoyer, J. 2006. Posttraumatic symptoms, depression, and anxiety of flood victims: The impact of the belief in a just world. *Personality and Individual Differences* 40: 1075–1084.

Ottosson, J. and Grahn, P. 2005. A comparison of leisure time spent in a garden with leisure time spent indoors: on measures of restoration in residents in geriatric care. *Landscape Research* 30: 23–55.

Pearce, D. 2003. The social cost of carbon and its policy implications. *Oxford Review of Economic Policy* 19: 362–384.

Perrin, P.M. and Daly, O.H. 2010. A provisional inventory of ancient and long-established woodland in Ireland *No. Irish Wildlife Manuals Series*. BEC Consultants for Environment, Heritage and Local Government.

Perrings, C., Naeem, S., Ahrestani, F., Bunker, D.E., Burkill, P., Canziani, G., Elmqvist, T., Ferrati, R., Fuhrman, J., Jaksic, F., Kawabata, Z., Kinzig, A., Mace, G.M., Milano, F., Mooney, H., Prieur-Richard, A-H., Tschirhart, J. and Weisser, W. 2010. Ecosystem services for 2020. *Science* 330: 323–324.

Perry, C.D., Vellidis, G., Lowrance, R. and Thomas, D.L. 1999. Watershed-scale water quality impacts of riparian forest management. *Journal of Water Resources Planning and Management* 125: 117–125.

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

Poole, G.C. and Berman, C.H. 2001. An ecological perspective on in-stream temperature: Natural heat dynamics and mechanisms of human-caused thermal degradation. *Environmental Management* 27: 787–802.

Posthumus, H., Morris, J., Hess, T., Neville, D., Phillips, E. and Baylis, A. 2009. Impacts of the summer 2007 floods on agriculture in England. *Journal of Flood Risk Management* 2: 182–189.

Potschin, M. and Haines-Young, R. 2011. Ecosystem Services: Exploring a Geographical Perspective. *Progress in Physical Geography* 35: 575–594.

Powe, N.A. and Willis, K.G. 2002. Mortality and morbidity benefits of air pollution absorption by woodland. *Social and Environmental Benefits of Forestry Phase 2*. Forestry Commission. Edinburgh.

Purser, P., Wilson, F. and Carden, R. 2009. *Deer and Forestry in Ireland: A Review of Current Status and Management Requirements*. Woodlands of Ireland.

Quinn, J.M. and Stroud, M.J. 2002. Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research* 36: 409–429.

Renou-Wilson, F. and Byrne, K.A. 2015. Irish peatland forests: lessons from the past and pathways to a sustainable future. In *Restoration of Boreal and Temperate Forests*. Eds. Stanturf, J.A and Madsen, P., 2nd ed., CRC Press pp. 321–335.

Renou-Wilson, F., Keane, M., McNally, G., O'Sullivan, J. and Farrell, E.P. 2008. Developing a forest resource on industrial cutaway peatland. *The BOGFOR Programme*. COFORD. Dublin.

Reubens, B., Poesen, J., Danjon, F., Geudens, G. and Muys, B. 2007. The role of fine and coarse roots in shallow slope stability and soil erosion control with a focus on root system architecture: a review. *Trees* 21: 385–402.

Reynolds, C. and Davies, P. 2001. Sources and bioavailability of phosphorus fractions in freshwaters: a British perspective. *Biological reviews* 76: 27–64.

Richardson, J.S., Shaughnessy, C.R. and Harrison, P.G. 2004. Litter breakdown and invertebrate association with three types of leaves in a temperate rainforest stream. *Archiv für Hydrobiologie* 159: 309–325.

Rimmer, D., Saunders, R. and Paim, U. 1985. Effects of temperature and season on the position holding performance of juvenile Atlantic salmon (Salmo salar). *Canadian Journal of Zoology* 63: 92–96.

Robinson, M., Cognard-Plancq, A.L., Cosandey, C., Durand, D.P., Führer, D.H., Hall, R., Hendriques, M.O., Marc, V., McCarthy, R., McDonnell, M., Martin, C., Nisbet, T., O'Dea, P., Rodgers, M., and Zollner, A. 2003. Studies of the impact of forests on peak flows and baseflows: a European perspective. *Forest Ecology and Management* 186: 85–97.

Rodgers, M., O'Connor, M., Muller, M. and Xiao, L. 2012. Suspended solid yield from forest harvesting on upland blanket peat. *COFORD Connects*. COFORD Dublin.

Ryan, D.K. and Kelly-Quinn, M. 2015. Effects of riparian canopy cover on salmonid diet and prey selectivity in low nutrient streams. *Journal of Fish Biology* 86: 16–31.

Ryder, E., de Eyto, E., Dillane, M., Poole, R. and Jennings, E. 2014. Identifying the role of environmental drivers in organic carbon export from a forested peat catchment. *Science of the Total Environment* 490: 28–36.

Scarpa, R., Chilton, S.M., Hutchinson, W.G. and Boungiorno, J. 2000. Valuing the recreational benefits from the creation of nature reserves in Irish forests. *Ecological Economics* 33: 13.

Silgram, M., Anthony, S., Fawcett, L. and Stromqvist, J. 2008. Evaluating catchment-scale models for diffuse pollution policy support: some results from the EUROHARP project. *Environmental Science and Policy* 11: 153–162.

Smith, G.F., Gittings, T., Wilson, M.W., Oxbrough, A., Iremonger, S., O'Donoghue, S., McKee, A.M., O'Halloran, J., Kelly, D.L., Pithon, J., O'Sullivan, A., Neville, P., Mitchell, F.J.G., Giller, P., O'Donnell, V. and Kelly, T. 2006. Biodiversity assessment of afforestation sites. *BIOFOREST Project Final Report*.

Stithou, M., Hynes, S., Hanley, N. and Campbell, D. 2011. Estimating the value of achieving "good ecological status" under the Water Framework Directive in the Boyne River catchment: a mixed multinomial logit approach. *SEMRU Working Paper Series No. 11*. Department of Economics, National University of Ireland Galway.

Sturt, M.M., Jansen, M.A.K. and Harrison, S.S.C. 2013. Invertebrate grazing and riparian shade as controllers of nuisance algae in a eutrophic river. *Freshwater Biology* 56: 2580–2593.

Sunderland, T. 2012. Microeconomic evidence for the benefits of investment in the environment – review. *Research Report*. Natural England.

Sweeney, O.F.M., Wilson, M.W., Irwin, S., Kelly, T.C. and O'Halloran, J. 2010. Are bird density, species richness and community structure similar between native woodlands and non-native plantations in an area with a generalist bird fauna? *Biodiversity and Conservation* 19: 2329–2342.

Teklehaimanot, Z. and Jarvis, P.G. 1991. Direct measurement of evaporation of intercepted water from forest canopies. *Journal of Applied Ecology* 28: 603–618.

Termansen, M., McClean, C.J. and Søndergaard Jensen, F. 2013. Modelling and mapping spatial heterogeneity in forest recreation services. *Ecological Economics* 92: 48–57.

Thimonier, A., Dupouey, J., Bost, F. and Becker, M. 1994. Simultaneous eutrophication and acidification of a forest ecosystem in North-East France. *New Phytologist* 126: 533–539.

Thomas, H. and Nisbet, T. 2007. An assessment of the impact of floodplain woodland on flood flows. *Water and Environment Journal* 21: 114–126.

Tobin, B., Black, K.G., Nieuwenhuis, M. and Gardiner, J. 2006. Biomass expansion factors and forest biomass C stares. In *Carbon Sequestration And Irish Forest Ecosystems*. Eds. Black, K.G. and Farrell, E.P., COFORD (National Council for Forest Research and Development), Dublin.

Tol, R.S.J. 2005. Adaptation and mitigation: trade-offs in substance and methods. *Environmental Science and Policy* 8: 572–578.

Townsend, M. 2006. Feel blue? Touch green! Participation in forest/woodland management as a treatment for depression. *Urban Forestry and Urban Greening* 5: 111–120.

Ulrich, R.S. 1981. Natural versus urban scenes: Some psychological effects. *Environment and Behavior* 13: 523–556.

Ulrich, R.S. 1983. Aesthetic and effective response to natural environment. In *Behavior and the Natural Environment*. Eds. Altman, I and Wohlwill, J.F., Pienum Press, New York, pp. 85–125.

UNECE/FAO. 2010. The European Forest Sector Outlook Study II 2010–2030. Geneva.

UNECE/FAO. 2013. Joint Wood Energy Enquiry 2009–2012.

Upton, V., Ní Dhubháin, Á. and Bullock, C. 2012. Preferences and values for afforestation: the effect of location and respondent understanding on forest attributes in a labelled choice experiment. *Forest Policy and Economics* 23: 17–27.

Upton, V., Ní Dhubháin, Á. and Bullock, C. 2012. The valuation of non-market forest benefits in Ireland: a review. *Irish Forestry* 68: 63–76.

Upton, V., O'Donoghue, C. and Ryan, M. 2014. The physical, economic and policy drivers of land conversion to forestry in Ireland. *Journal of Environmental Management* 132: 79–86.

Upton, V., Ryan, M. and O'Donoghue, C. 2014. A spatially explicit national demand model for forest recreation in Ireland. Presented at Agricultural Economics Society 88th Annual Conference, 10th April 2014, Paris, France.

van Dijk, A.I. and Keenan, R.J. 2007. Planted forests and water in perspective. *Forest Ecology and Management* 251: 1–9.

Vinebrooke, R.D. and Graham, M.D. 1997. Periphyton assemblages as indicators of recovery in acidified Canadian Shield lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 1557–1568.

Walther, G.R. 2010. Community and ecosystem responses to recent climate change. *Philosophical Transactions of the Royal Society B: Biological Sciences* 365: 2019–2024.

Webb, B. and Crisp, D. 2006. Afforestation and stream temperature in a temperate maritime environment. *Hydrological Processes* 20: 51–66.

Wilkerson, E., Hagan, J.M., Siegel, D. and Whitman, A.A. 2006. The effectiveness of different buffer widths for protecting headwater stream temperature in Maine. *Forest Science* 52: 221–231.

Wilson, M.W., Gittings, T., Pithon, I., Kelly, T.C., Irwin, S. and O'Halloran, J. 2012. Bird diverstiy of afforestation habitats in Ireland: Curretn trends and likely impacts. *Ecology and Environment Proceedings of the Royal Irish Academy* 1120: 43–56.

Wolf, K., Mass, R., Kiefer, F., Wiedemann, K., Naber, D., Debnath, M., Das, S.K., Bera, N.K., Nayak, C.R. and Chaudhuri, T.K. 2006. An epidemiologic study of posttraumatic stress disorder in flood victims in Hunan China. *Canadian Journal of Psychiatry* 51: 350–354.

Wood, P.J. and Armitage, P.D. 1997. Biological effects of fine sediment in the lotic environment. *Environmental Management* 21: 203–217.

Zhang, L., Dawes, W.R. and Walker, G.R. 2001. Response of mean annual evapotranspiration to vegetation changes at catchment scale. *Water Resources Research* 37: 701–708.

Socio-economic drivers of farm afforestation decision-making

Mary Ryan[a*] and Cathal O'Donoghue[b]

Abstract
The decision to convert land from agriculture to forestry has previously been considered in a number of studies which have variously assessed attitudinal and economic factors affecting the afforestation decision. However, none of these studies has fully taken into account the heterogeneity of individual farms in Ireland, particularly in terms of farm and farmer characteristics. This review paper presents a summary of recent research undertaken by the authors which delves deeper into the economic decision-making process at the individual farm level by examining the characteristics of the farms and farmers that planted land and comparing them to those farms without forests over almost 30 years, using data from the Teagasc National Farm Survey. The results show that soil type and the agricultural market income and subsidies prevailing in the year of planting all have an effect on the economic attractiveness of afforestation. The potential relative returns to both agriculture and forestry on these farms was also investigated and was found to be a significant driver of the afforestation decision. The research presented also shows that the drivers of afforestation decisions may be influenced by contemporaneous farm management decisions. The results of an additional survey undertaken in 2012 highlight the magnitude of the challenge facing policy makers in designing afforestation incentive schemes as 84% of farmers surveyed would not consider planting in the future, regardless of the financial incentives offered. This challenge is particularly important in relation to national objectives to move to carbon neutral farming in the medium term. Drawing on the behavioural economics literature, the authors present a range of policy measures that go beyond financial incentives that could potentially increase afforestation rates.

Keywords: *Farm afforestation, decision-making, behaviour, carbon sequestration, GHG mitigation.*

Introduction
Forests are increasingly valued as a natural resource and for their potential to enhance ecosystem services (Kanowski 2010). Thus increasing forest cover is an important policy objective across many EU countries (EU Commission 2013). Forest cover expansion is included as a source of carbon dioxide emission reduction under the Kyoto Protocol, which is a significant factor in the promotion of forest expansion policies (Nijnik and Bizikova 2008). In common with other EU member states, Ireland has sought to increase its forest cover for some time, with rural employment and economic diversification benefits being important drivers in the 20th Century, while broader ecosystem services have been increasingly recognised in modern Irish forest policy (DAFF 1996, OCarroll 2004, DAFM 2014).

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Yet in recent years, the rate of afforestation in many European countries has been declining (Eurostat 2013). In Ireland, despite the availability of strong financial incentives, afforestation has fallen short of policy targets over the last 20 years. This has long-term consequences for downstream timber processing, for the wood fibre supply for renewable energy and fossil fuel displacement and for the potential of forests to sequester carbon. This is compounded by competing demands for land to provide these services in addition to expanding agricultural production to meet global food demands (FAO 2009). The largest constraint on the expansion of both agriculture and forestry is land availability, which is limited by biophysical, biological and environmental restrictions (Farrelly and Gallagher 2015). The availability of land for afforestation in Ireland is currently under review (COFORD 2016). Agricultural expansion is also likely to be constrained by limits on greenhouse gas emissions. The ability of forests to sequester carbon and mitigate greenhouse gases generated by the agriculture sector, could potentially facilitate agricultural expansion. Thus, a holistic examination of all aspects of the afforestation decision is merited.

The conversion of land from agriculture to forest involves a complex decision-making process and the influencing factors can be difficult to isolate. Physical, economic and behavioural drivers that are relevant to the afforestation decision can be identified from literature:

- soil quality and the resultant forest productivity;
- financial incentives;
- opportunity cost of planting;
- relativity of agricultural and forest income streams;
- permanence of land use change from agriculture to forestry;
- changes in farming intensity associated with planting;
- socio-cultural attitudes towards afforestation.

The forest economics modelling capacity developed by Teagasc in recent years facilitates a broad range of analytical techniques to assess the impact of these drivers. In the context of addressing the role of farmers in relation to potential future expansion of afforestation, this review paper focuses on drawing on lessons from this economics research programme in order to inform future policy options. The farm level and behavioural drivers that influence the inter-temporal land use change from agriculture to forestry are examined in order to ascertain whether there is a relationship between the relativity of forest and agriculture income streams and the likelihood of planting. To do this we first examine the physical and policy drivers of the economic returns to farm forestry and the associated agricultural opportunity cost foregone. We examine the characteristics of farms with forests and also examine farm decisions contemporaneous to the year of planting, to inform the degree to which the decision to afforest land is merely a substitute land use or alternatively, is part of the long-term objectives of the farm. The results are discussed in relation to the design of future afforestation incentive measures.

Policy context

Ireland's forest policy has undergone a number of significant changes in emphasis since the founding of the State when forest cover represented just one per cent of the land area, to the current forest cover of 11%. Successive forest policy strategies have set policy objectives and annual targets for private sector afforestation. Following high levels of annual afforestation in the early 1990s, the ambitious planting targets of 20,000 and 25,000 ha yr^{-1}(DAFF 1996)[1] were revised downwards as afforestation started to decline (See Figure 1). Since 2005 even these reduced targets have not been met, despite the higher forest premium payments in place over this period. This may be explained in part by previous research which shows that forest subsidies available to many farmers (since 1984) have been less attractive financially than the subsidies associated with remaining in cattle farming (Ryan et al. 2014).

The most recent revision of forest policy (DAFM 2014) re-affirms the importance of forestry as a national land use policy and sets targets to increase the total area under forest to 18% of the land area by 2046. This is in part due to the need to maintain and increase the store of carbon sequestered in Irish forests (Hendrick and Black 2009).

In the wider land use context, the drive to produce more food to feed the rapidly expanding global population has led to the development of Irish agricultural expansion strategies (Food Harvest 2020 and Food Wise 2025 (DAFF 2010, DAFM 2015). Due

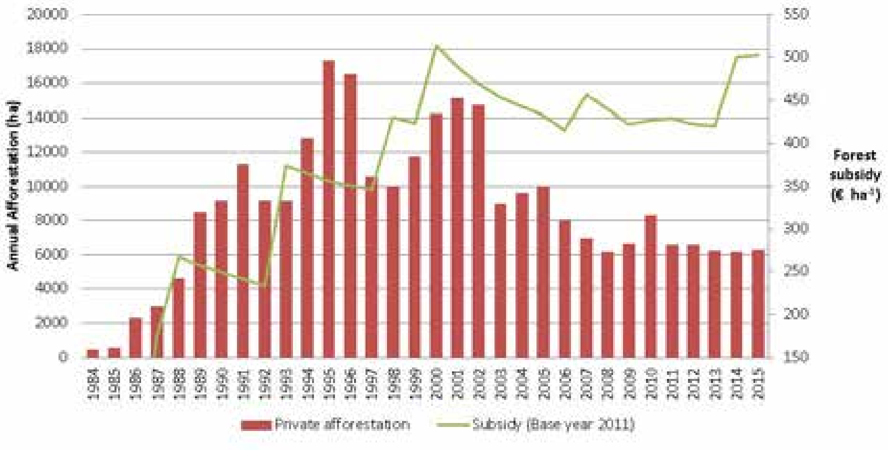

Figure 1: *Annual private afforestation (ha) and forest premium payments (€ ha^{-1}expressed as 2011 values) for Sitka spruce conifer plantations (1984 to 2015). Source: DAFM 2015 and author's personal data.*

[1] To achieve forest cover of 17% by 2030.

to the large role played by the agri-food sector in the Irish economy, agriculture already accounts for 33% of total national greenhouse gas (GHG) production (EPA 2015). Thus it is likely that expansion will be constrained by EU Climate and Energy policies that impose limits on the level of carbon that can be released to the atmosphere in the form of GHGs.

A number of pathways to reduce or mitigate agricultural GHG production are currently being investigated. These include efficiency measures such as the reduction of "per kilo of product" emissions from the production of food products (Ryan et al. 2015a); identifying technologies to reduce emissions directly (Lanigan and Richards 2014); and integrated land management options such as increasing carbon sequestration through increased afforestation (Schulte et al. 2013). The decision of the EU Council of Ministers (EUCO 2014) to allow for the inclusion of Land Use, Land Use Change and Forestry (LULUCF) in the 2030 greenhouse gas mitigation framework opens up the possibility of pursuing "carbon neutrality" as a horizon point for Irish agriculture, whereby "national GHG emissions from agriculture are fully offset by carbon sequestration by grassland soils, forestry and other land use" (NESC Secretariat 2013).

The permanent nature of the afforestation decision

However the complexity of the decision to change land use from agriculture to forestry in Ireland is increased by the fact that the decision essentially involves a permanent land use change. Under the 2014 Forestry Act, it is necessary to acquire a felling licence prior to harvesting timber from forests. In general, one of the conditions imposed by the relevant Minister on granting the licence is the replanting of the harvested forest. This imposes a restriction on the flexibility of land use and a substantial replanting cost which is currently not compensated to the forest owner.

Theoretical context

On many levels, farming and forestry differ hugely as land uses. Factors such as inherent preferences for either forestry or farming, the externalities generated by forests, the risks associated with long-term investments, the length and permanent nature of the forest rotation are specific to forestry and must be taken into account in an analysis of the land use change.

Theory of land use change

In understanding the economic drivers of land use change, we need to understand the differential preferences and returns to farming (F) and forestry (trees) (T). Traditional economic theory suggests that individuals make decisions based on the expected change in their level of "well-being", where the term used for well-being or welfare is "utility" (Edwards-Jones 2006). Thus economists use utility maximisation frameworks, rather than profit maximisation frameworks in determining the drivers of behaviour.

We can describe the utility (U) or happiness that derives from alternative land uses i.e. farming and forestry (L_F and L_T), in terms of returns to land use (p_F and p_T) and farmer preferences for either farming or forestry, respectively α and β

$$U = \alpha . L_F . p_F + \beta . L_T . p_T \qquad [1]$$

where $\alpha > \beta$ as we already know from literature that farmers generally prefer to farm than to afforest land (Ní Dhubháin and Gardiner 1994, Duesberg et al. 2013, Howley et al. 2015).

In economics, the marginal rate of substitution (MRS) is the rate at which a consumer is ready to give up one good in exchange for another good while maintaining the same level of utility. In developing an understanding of the MRS between Farming (F) and Forestry (T) planting, we model the ratio of marginal utility.

Marginal rate of substitution between farming and forestry:

$$\begin{aligned} MRS_{FT} &= \frac{MU_F}{MU_T} = \frac{\delta U}{\delta L_F} . \frac{\delta L_T}{\delta U} \\ &= \alpha p_F . \frac{1}{\beta p_T} \\ &= \frac{\alpha p_F}{\beta p_T} \end{aligned} \qquad [2]$$

If the return to land use from farming is the same as planting a forest, i.e. if $p_F = p_T$, then

$$MRS_{FT} = \frac{MU_F}{MU_T} = \frac{\alpha}{\beta} > 1$$

This implies that farmers prefer to farm rather than plant forests and tells us that in order to counter-balance these preferences, the return to land use needs to be higher from forestry than from farming. This also applies, due to inertia, to any move from the *status quo* to an alternative land use.

Marginal private benefit and marginal social benefit

Afforestation, results in the provision of public goods in the form of carbon sequestration so that the benefits from planting forestry extend beyond those of the farmer. Such public benefits arising from private land are known as externalities which can be positive in the case of public goods such as carbon sequestration, or negative in the case of atmospheric emissions or pollution (public bads). The rationale for the state to "step in" to control pollution arises from the existence of these externalities, which are costs (or benefits) imposed by the polluter on others.

In theory, farmers should plant when the marginal private benefit equals the marginal private cost. In other words, the extra income and costs, respectively, associated with an incremental land use change into forestry, at least balance each other out. However as the benefits to society are larger due to the presence of externalities, the socially optimal intersecting point is located at a higher level of forestry than is privately optimal (see Figure 2). This difference motivates the concept of Pigouvian subsidies, or payments to the provider of the public good, to equalise the marginal social benefit and the marginal private benefit. If this happens, then in theory, the level of planting would be expected to coincide with the socially optimal level.

Forestry is also associated with other risks such as fire and storms (wind blow) which can cause extensive damage (as in the case of Storm Darwin in 2014). Natural disasters have a low probability of occurrence in any particular stand of timber but research suggests that forest damage caused by disturbance is increasing (Schelhaas 2008). Without the support of a well-developed insurance market, farmers or potential investors may be reluctant to consider forestry as an option (Zhang and Stenger 2014).

The timing differential of agricultural and forest income streams was the motivation for the historic structure of policy payments with upfront forest establishment subsidies (grants) and annual forest premium payments until timber revenues arise. The higher

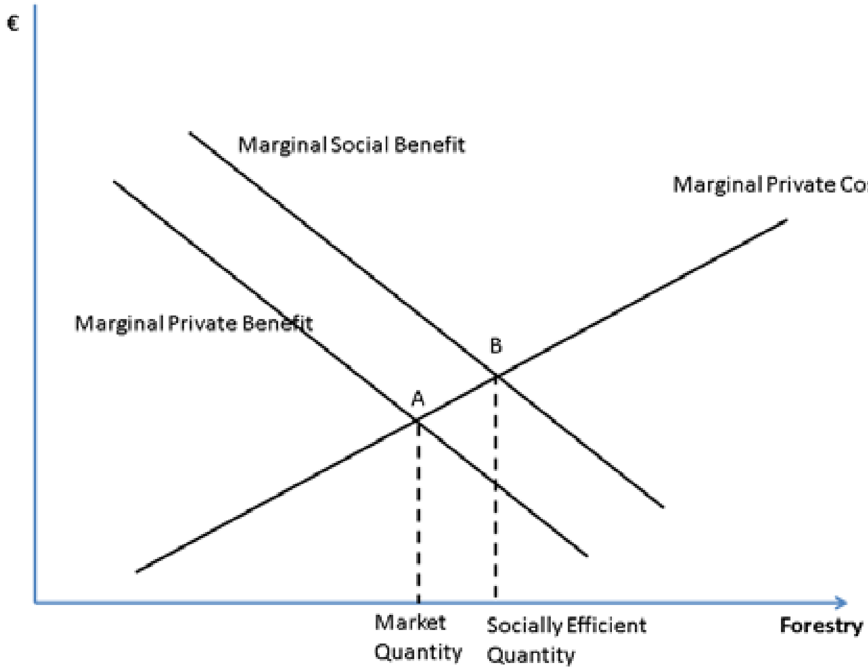

Figure 2: *Marginal social benefit and marginal private benefit of afforestation.*

[2] In the presence of positive externalities, those who receive the benefit do not pay for it and the market may under-supply the product. Similar logic suggests the payment of a Pigouvian subsidy to make the users pay for the extra benefit would spur more production

preference for income now, relative to future income, (known as the discount rate), means that there is less incentive for a land use change that substitutes current income from farming for future income from forestry. The question that arises here is whether the structure of these subsidy schemes sufficiently mitigates this preference.

Socio-economic drivers of farm afforestation decision-making

Life-cycle returns

The economic return to farm afforestation is comprised of two elements – the return to afforestation given the particular soil and environmental context of an individual farm; and the income foregone from the superseded agricultural enterprises on that farm. In turn, both agricultural and forest incomes are comprised of market and subsidy components. Thus, there are both physical and policy drivers of the economics of farm afforestation.

Afforestation involves significant establishment costs at the start of the life-cycle, followed by "lumpy" thinning returns with the majority of income arising at the point of harvesting (see Figure 3). This compares with a "flatter" income profile from the alternative land use of farming.

Therefore a life-cycle approach such as the calculation of net present value[3] (NPV) of alternative income streams is necessary when comparing the two land uses. Both the agricultural and forest income streams are calculated as the sum of the present

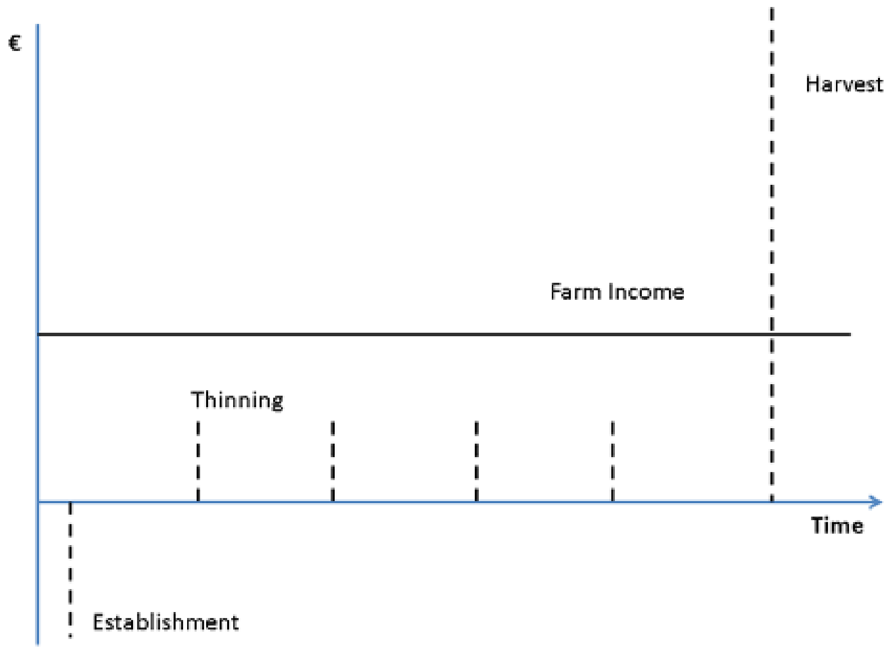

Figure 3: *Timeline of income streams of farming and forest income.*

[3] NPV is the discounted value of net incomes over a rotation, presented in today's money.

values of the annual net amounts (revenue less costs) in the income stream (assuming a constant discount rate (r) where n = year in which cost/revenue occurs).

$$NPV = \frac{I_0}{(1+r)^0} + \frac{I_1}{(1+r)^1} + \frac{I_2}{(1+r)^2} + \cdots + \frac{I_n}{(1+r)^n} = \sum_{i=0}^{n} \frac{I_i}{(1+r)^n} \qquad [3]$$

The forest income stream varies over time whereas the agricultural income stream is held constant over the forest rotation as illustrated in Figure 3. The NPVs of forest and agricultural income streams are generated for the forest rotation and converted to annualised equivalent (AE) values to facilitate comparison with farm income measures where:

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

Measuring net present value of afforestation

In analysing the economic return to forests, a forest bio-economic systems model[4] (Ryan et al. 2016) is utilised to generate annual equivalised (AE) NPVs of forest income streams for a range of forest productivity (yield) classes. These forest yield classes measure timber productivity in terms of the average volume production per hectare per year. Figure 4 illustrates the larger (AE) NPV achieved by higher yield classes and shows a strong upward trend in forest (subsidy plus market) incomes over time, regardless of yield class.

Yield class also affects the share of forest subsidies in overall forest income as the trend in Figure 5 is consistent over time. For higher yield classes, subsidies form a relatively small proportion of income, but for the lowest yield class, the share of subsidies rises to 100% of income during the period examined. Model outputs show that life-cycle forest incomes vary little with yield class in the early years as income is derived from grant and premium subsidies. However, once forest subsidies cease and thinning commences, higher yield classes have a larger effect on the economic return to forestry. Further research undertaken by Ryan et al. (2016) shows that there is little qualitative difference in (AE) NPV when analysing the economic return from one rotation or from a larger number of rotations (at 5% discount rate) as the value accruing from harvests is so far into the future that it is heavily discounted.

Agricultural subsidy effects

In order to determine the share of subsidies in agricultural incomes, Ryan (2016) examines two measures that include agricultural subsidies. These are presented in Figure 5.

Farm Gross Margin (GM) is a broad measure of output as only direct costs

[4] The forest bioeconomic systems model (ForBES) generates cost and income curves for a range of yield classes and thin and no-thin scenarios and generates annual equivalent NPVs for a range of discount rate, subsidy, rotation and indexation options.

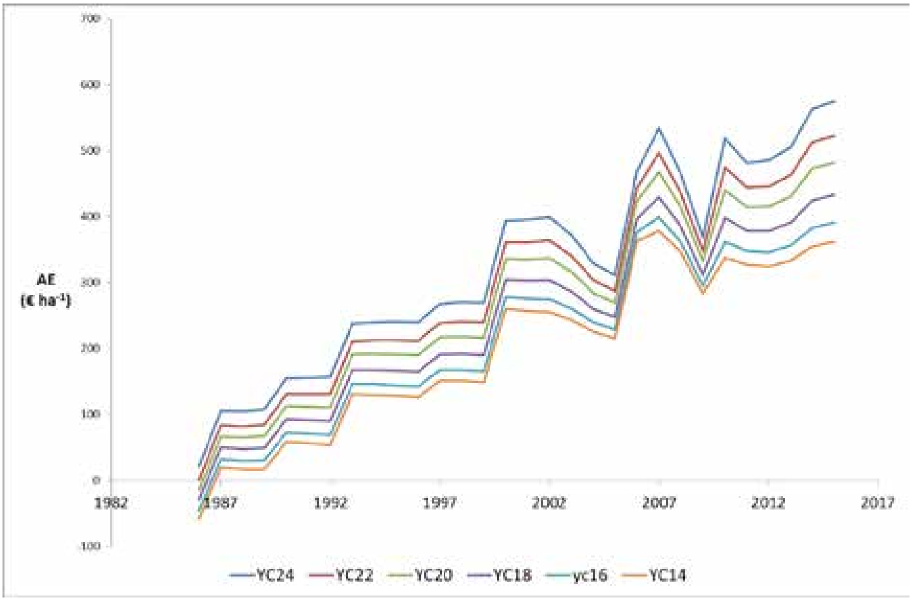

Figure 4: *Annual equivalised forest NPVs (€ ha^{-1}) (1985-2013). Source: Teagasc Forest Bio-Economic Systems Model (Ryan et al. 2016).*

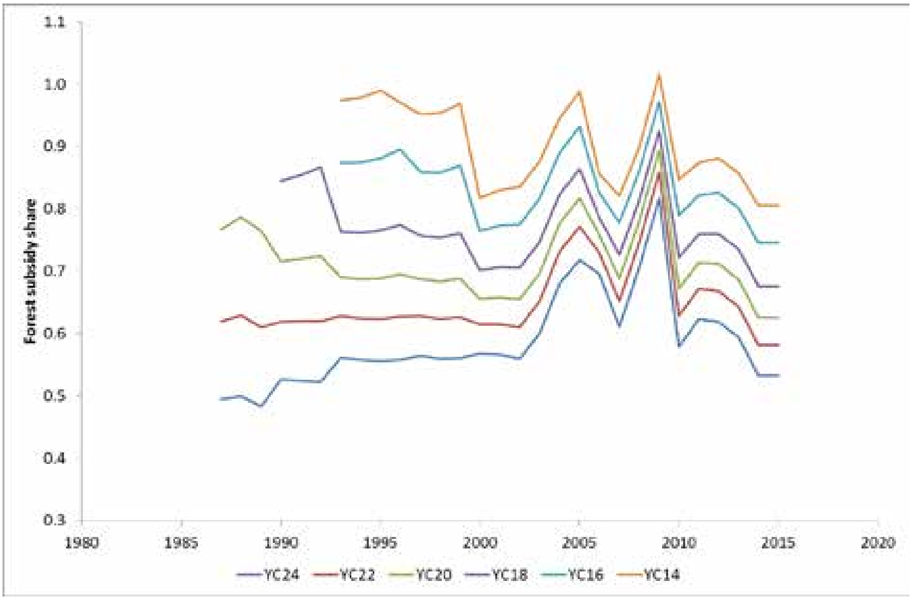

Figure 5: *Share of subsidies in forest income streams (1985-2013). Source: Ryan (2016).*

such as fertilisers and feed stuffs are deducted. As overhead costs are not deducted, GM can be used in making short term decisions, while Family Farm Income (FFI) is a longer-term measure of agricultural incomes. Figure 6 shows that there is a

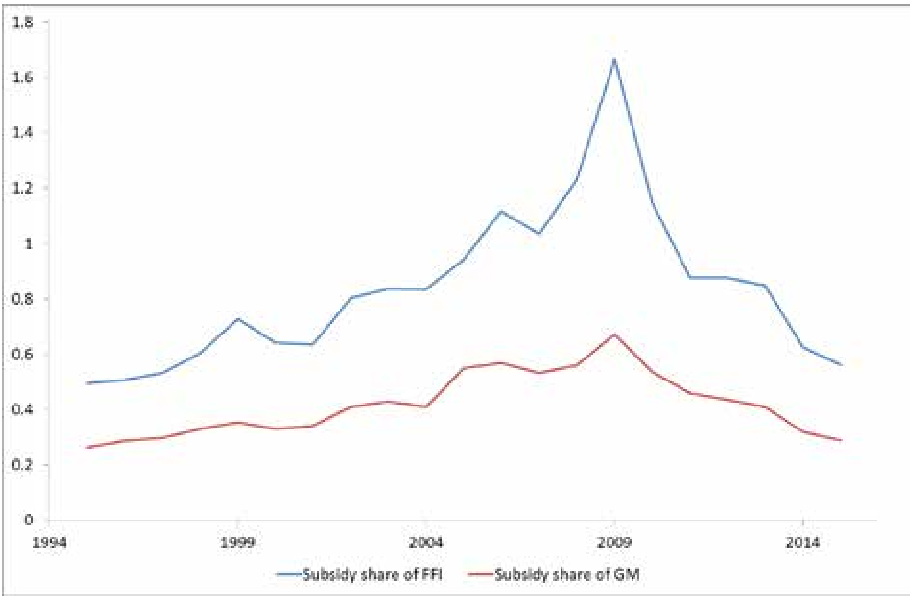

Figure 6: *Share of agricultural subsidies in agricultural incomes measured using Family Farm Income (FFI; € ha^{-1}) and Farm gross Margin (GM; € ha^{-1}) over time. Source: Ryan (2016).*

considerable difference in the magnitude of the share of subsidies for the measures used as the share is higher in the FFI measure of farm income. The trend is similar for both measures as the share rises steadily over time, reflecting a number of increases in agricultural subsidies (McCormack and O'Donoghue 2014). The share of subsidies peaks in the poor market income year of 2009 and declines as a component of income following a recent period of strong market income increases (Hennessy and Moran 2015). This partially explains the reluctance of some farmers to plant as the expectation of future subsidies is recognised as having affected land use decisions as farmers position themselves to ensure they retain eligibility for payments (O'Donoghue and Whitaker 2010). This flexibility no longer exists once land is afforested.

The impact of soil type on economic return

A common measure of productivity is necessary to compare agricultural and forest productivity as represented by forest yield classes and agricultural soil classes. On the basis of their relative productivity for either agriculture or forestry, Upton et al (2013) present the assignment of forest yield class (YC) estimates for Sitka spruce (*Picea sitchensis* (Bong.) Carr.) to NFS agricultural soil classes (SC)[5] which allows for the categorisation of farm data in relation to the relevant Sitka spruce yield class: SC1 and YC24 reflect the highest level of productivity for either agriculture or forestry (Table 1).

[5] Soil Classes (SC) range from SC1 (suitable for wide use) to SC6 (extremely limited for agriculture).

Upton et al. (2013) also shows that in the context of farm afforestation, different farm systems have different opportunity costs as presented which presents the average NPV of a land use change from the NFS farm systems to a conifer (SS) forest (Table 1). On average, the opportunity cost of replacing a dairy enterprise with forestry is high across all yield classes. Therefore the NPV is negative across all soil classes. In making the decision to plant some of their agricultural land, it is assumed that farmers are unlikely to plant land which gives a higher return in another farm enterprise, (such as dairy) thus it is more likely that cattle and sheep farmers with positive returns from planting are more likely to plant.

Agricultural opportunity costs

The values presented in Table 1 are averages across each farm system. In reality, there may not be any "average" farmers so the information that can be gleaned from using average values is limited as approaches which utilise averages do not take account of both farm and farmer efficiencies at the individual farm level. To assess the economic impact of afforestation on farm incomes for individual farms over a forest rotation, Ryan and O'Donoghue (2016) generate income streams for the life-cycle of the proposed afforestation and for the superseded agricultural enterprise (for each planting year from 1985 to 2013, for each farm in the NFS pooled dataset on a per hectare basis). This allows for the investigation of individual farm and environmental characteristics such as soil class, farm system, farm size and livestock density, as well as the impact of subsidies and market prices over the period. While the NFS is not representative of small farms, it is representative of 95% of Standard Output from agriculture and accounts for 81.3% of total Utilisable Agricultural Area (UAA) (Hennessy and Moran 2015).

Soil and policy effects over time

In untangling the effects of decoupling of payments from production, we examined 1998 and 2007 as being representative of the post-MacSharry (coupled payments) and the Single Farm Payment (SFP) (decoupled payments) periods, respectively. Ryan (2016) calculated opportunity costs as the annual forest income stream less

Table 1: *Average soil category (SC) specific NPVs (2009 € ha^{-1}) for forestry replacing the main agricultural systems. Adapted from Upton et al. (2013). Values adjusted using the consumer price index and expressed according to 2009 values.*

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

the agricultural income foregone for each year of the forest life-cycle and presented them as Net Farm Afforestation Income (NFAI) per hectare. In summary, Ryan (2016) observed the following in relation to the effect of soil code and year of planting on the net return to farm afforestation:

- It is evident that when higher agricultural incomes (such as those represented by dairy, dairy other and tillage on better soils) are deducted from the forest income stream, the net benefit of afforestation is likely to be negative. Afforestation does not compete financially with the dairy system under any soil conditions, regardless of whether a gross or a net measure of agricultural income is used in the calculation of the opportunity costs. The income patterns for dairy other and tillage are similar to dairy.
- In contrast, farmers engaged in livestock enterprises are the most likely to benefit financially from converting land to forestry, particularly in the latter years of the period. The significance of these results for potential future afforestation lies in the relative size of the livestock sector in Ireland. Livestock systems (cattle rearing, cattle other and sheep) account for over 68% of farms, and the cattle systems alone make up more than half the farms in Ireland (Hennessy and Moran 2015).
- The effect of year of planting on economic return has a large impact as all systems have negative NFAI in 1998 (except for the sheep, tillage and dairy other systems on poorer soils) while the NFAI of afforestation in 2007 is positive (in other words the opportunity cost is lower). The higher NFAI in 2007 is due to (a) market variation rather than subsidies, as market income in 2007 is considerably higher and (b) the effect of subsidies is stronger in the earlier period as farmers would have lost coupled payments on planting however, this is not the case in the later period as farm afforestation is eligible for SFP, reducing the agricultural opportunity cost foregone.

Analysis of the relative profitability of agriculture and forestry on individual farms

Many Irish studies have found that the relative profitability of agriculture and forestry are significant factors in determining afforestation rates in Ireland (see McKillop and Kula (1988), Behan (2002), McCarthy et al. (2003), Breen et al. (2010), Upton et al. (2013)). To characterise farms on the basis of whether they would be better off financially if they planted land or not, Ryan and O'Donoghue (2016) generate variables (Ag >For) to denote farms where the potential life-cycle agricultural income is greater than that from forestry and (For >Ag) where the life-cycle forest income is greater. Ryan and O'Donoghue (2016) examine the sample of farms that planted in the past and those that might plant in the future. Summary statistics from this research are presented in Table 2 where life cycle forest income streams are defined as (AE) NPV of market plus subsidy income. In order to disentangle the effect of agricultural subsidies, agricultural income streams are defined as farm gross margin with subsidies (NPV1) and without subsidies (NPV2). Farms are further categorised on the basis of having farm forests i.e. "Has Forest" and "No Forest".

The calculation of NPV is sensitive to the inclusion of subsidies as the percentage of farms with higher forest incomes drops from 40%) to 25% when agricultural subsidies are explicitly taken into account (NPV1), however, the inclusion of agricultural subsidies in the calculation of the opportunity cost is less relevant for future rather than historic afforestation.

Only 13% of farms in the pooled dataset have forests and that the majority of farms have higher agricultural incomes and haven't afforested land. This is consistent with *a priori* expectations as these farms have the highest opportunity cost. The smallest group describes farms where the forest income is higher than the agricultural income but these farmers already have forests. However, there is a considerable percentage of farms (21% incl. subsidies and 34% without subsidies) that have higher forest incomes but these farms do not have forests.

Post-planting consequential farm management changes

The partial replacement of a livestock enterprise with forestry has consequences for the management of the farm as a whole. In investigating whether the afforestation decision involves a straight land use substitution which is made in isolation, or is alternatively part of a more complex lifestyle decision-making framework, Ryan and O'Donoghue (2016) examine changes in the level of intensity of farming by looking at the stocking density (year before planting versus year of planting) for all farms with forests in the NFS 2012 Supplementary survey dataset. The results show that the average stocking rate reduces from 1.44 to 1.37 LU ha^{-1}. On just under one third of farms with forests, there is no change in livestock density in the

Table 2: *Relative profitability of agriculture and forestry for farms with or without forests. Source: Ryan and O'Donoghue (2016).*

	Gross Margin (incl. subsidies) (NPV1)		**Market Gross Margin (no subsidies) (NPV2)**	
	Frequency	**%**	**Frequency**	**%**
Ag>For/No For	23,546	66	18,772	52
Ag>For/Has For	3,385	9	2,648	7
For>Ag/No For	7,394	21	12,168	34
For>Ag/Has For	1,439	4	2,176	6
Total	35,764	100	35,764	100

Note: income components are on a per hectare basis. NPV's were to an annualised definition, dividing by, varying with the forest rotation for the relevant yield class and soil type.

year of planting. A quarter of farms increase stocking rate (by more than 5%) while the largest proportion of farms (43%), reduce livestock density (by more than 5%) in the year of planting (Ryan and O'Donoghue 2016). On the basis of analysis of the characteristics of these three farming intensity cohorts, Ryan and O'Donoghue (2016) put forward three discrete intensity objectives or farming "mind-sets".

Farms that don't adjust the livestock density per hectare after planting are the largest and most intensive farms with the highest average livestock density, highest dairy livestock density, highest average hours worked and the highest average farm income. Less than one third of these farms have a higher NPV of income from forestry than from agriculture. These farms were already reasonably heavily stocked (average 1.6 LU ha^{-1}) so they had no choice but to reduce stocking density as a result of having less land available for grazing. It is likely that these farms did not have spare capacity in terms of land and took an economic decision to optimise their land use replacing a marginal agricultural enterprise with a more productive forestry enterprise. These farms may be characterised by having an "intensive/optimisation" mindset.

For the 25% of farmers who increase intensity as a result of afforestation, forest income is greater than agricultural income on almost half (47%) of these farms They have a slightly smaller average farm size of 62 ha and the lowest farm income, are younger and are more likely to have off-farm income, suggesting that these are part-time farmers who have planted excess land which they did not need as they maintain similar or greater stock numbers on a reduced land area. These are farmers who may be optimising their work hours by planting land to free up time to supplement overall income with off-farm income. These farmers could be characterised as having a "diversification" mind-set.

However, 44% of farms decrease their stocking rate suggesting that these farms may be "winding down". Prior to planting, this group had high average stocking densities and just over half of these farms have higher incomes from forestry. The farms are smaller on average (55 ha) and the farmers are older. They are more likely to be in agri-environment schemes and have considerably higher direct payments than the other groups. These farmers appear to have a "de-intensification" mind-set.

In summary, it would appear that the decision to afforest land involves consequential decisions in relation to farming intensity. At the very least, this involves decisions in relation to livestock density, but it would also appear that the decision to afforest may be part of wider lifestyle decision-making.

Behavioural drivers of farm afforestation decision-making

Frawley and Leavy (2001), Ní Dhubháin and Gardiner (1994) and Duesberg et al. (2013) all cite reluctance among Irish farmers to plant land that is "good" for farming. McDonagh et al. (2010) find that the most important barriers to planting are (1) the desire to farm and (2) the permanent nature of forestry. In Scotland, the Mindspace (2010) survey reports that for one third of Scottish farmers who hadn't planted, there was "nothing that would persuade them to plant", while in England, Watkins et al. (1996) find that most farmers did not want woodland on their farmland. Farmers interviewed by Duesberg et al. (2014) present the most simplistic view, ascribing their reluctance to engage in forestry as "…simply because it is not farming".

On this basis it makes sense that there exists a cohort of farmers who choose not to plant, regardless of the relativity of forest and agricultural income streams. This apparent contradiction has been commented on previously in the Irish farm afforestation context (see Breen et al. 2010, Upton et al. 2013, Howley et al. 2015). However, the size of this cohort of farmers has not been determined until an examination of attitudinal data from the 2012 NFS supplementary survey undertaken by Ryan and O'Donoghue (2016) revealed that over 84% of farms do not intend to afforest their land at any level of forest subsidy.

On the basis of this information, Ryan and O'Donoghue (2016) further categorise farms in relation to afforestation intentions i.e. "Might Plant" and "Never Plant", on the basis of whether these farms would have higher incomes from forestry or from agriculture (calculated with and without the inclusion of agricultural subsidies).

Despite the fact that the largest agricultural subsidy i.e. the Basic Payment (formerly Single Farm Payment) is payable on afforested land, the influence of subsidies is still strong as over 65% of farms would have higher forest income (on a per hectare basis) when agricultural subsidies are not taken into account, but this drops to over 36% when agricultural subsidies are included in the calculation of the NPVs (Table 3). It is also evident that while some farmers who would consider planting would have a higher potential agricultural income, there is a large proportion of farms will not plant even when their potential forest income per hectare is higher.

Characteristics of farmers who might plant / will never plant

Table 3: *Farms in 2012 NFS Supplementary Survey farms categorised according to intention to plant and by relative Agriculture and Forest incomes under different NPV measures. Source: Ryan and O'Donoghue (2016).*

	Total	**NPV1 (GM incl. subs)**		**NPV2 (MGM)**	
		Ag >For	**For >Ag**	**Ag >For**	**For >Ag**
Might plant	15.8	9.7	6.1	5.8	10.0
Never plant	84.2	54.1	30.1	28.8	55.4
Total	100.0	63.8	36.3	34.6	65.4

The characteristics of the 16% of farms and farmers that might plant in the future depending on the financial incentives offered are most interesting for those interested in incentivising further afforestation:

- Those with higher agricultural income streams are intensive farmers: they had high FFI, high dairy stocking rates and large farms, making it unlikely that they would plant unless forest income streams were comparable to or greater than the income from agriculture.
- On the other hand, of those farms that might plant and that have higher forest incomes, almost half (on average) have an off-farm job. These farms also had less productive soils. Their willingness to consider afforestation is possibly a diversification strategy to optimise both their land and their time resources. Farms that participate in agri-environmental schemes and have a (Teagasc) extension contract are more likely to have forests.
- The results of additional regression analysis also show that the relationship between the relativity of income streams and the likelihood of considering forestry in the future is significant and positive indicating that those farms with higher forest incomes are more likely to (might) plant (for both methods of NPV calculation) (Ryan and O'Donoghue 2016). In addition, the most consistently positive explanatory variable in all the analyses reviewed in this paper is farm size. This is also the experience of other studies in the literature that have included farm size as a variable (Duesberg 2013, Howley 2015).

Utility maximisation

Using micro-level data, Ryan et al. (2015b) estimate structural choice models which consider the revealed preferences or utility maximising decisions of farmers in the pooled dataset, when presented with a range of (11) afforestation choices to plant from zero to 50% of their land. A behavioural choice model that assesses how farms maximise their utility when presented with choices to plant between 0 and 50% of their land, reveals that initial "hurdle" of moving from 0 to 5% afforestation is significant and that on balance, many farmers prefer to farm than to afforest land, even if the income from forestry is higher. There is solid evidence that the gain in (forest) income is not sufficient to off-set the decrease in agricultural income, perceived decline in wealth, loss of flexibility of land use and overall loss of utility derived from farming. In addition, while farmers have a preference for more income, the value that farmers place on income derived from agriculture is three times that of income derived from forestry Ryan et al. (2015b).

Discussion

The preferences for agricultural income, land value and hours worked reflect conclusions in the literature in relation to non-pecuniary benefits of farming (Howley et al. 2015, Key and Roberts 2009) and preferences for more flexible uses of land (Duesberg 2013), resulting in low uptake of planting choices.

The largest barriers to afforestation highlighted are the desire to farm and the permanence of afforestation. Critically, in relation to self-assessed land value, Ryan and O'Donoghue (2016) note that farms with forests reduce the self-reported land value after planting. This is likely to reflect the loss of flexibility of land use caused by the permanence of the land use change to forestry. In addition, for many farmers the afforestation decision involves a wider complex of contemporaneous multi-enterprise farm decisions. On a higher level, this involves lifestyle decisions about the future direction of the farm business.

We know from the literature that there is a growing recognition that farmers are motivated by a range of socio-economic factors and that financial gain may not be their core motivation for farming. The low uptake of policy incentives for woodland creation in the UK was examined by Lawrence and Dandy (2014) who find that insufficient financial incentives, the long term nature of the investment and socio-cultural factors act as barriers to uptake and conclude that socio-cultural factors have a larger role in the afforestation land use change decision than previously acknowledged.

The percentage of farmers that will not consider afforestation (84%), regardless of the financial incentives involved, is an important finding. The analysis undertaken by Ryan and O'Donoghue (2016) reveals that these are older farmers who would benefit financially from afforestation but for whom negative cultural attitudes appear to be stronger than financial drivers. This is however not surprising as annually, only 3-4% of NFS farmers state their intention to plant within a three year period (Ryan and Kinsella 2008).

On a more positive note, this analysis also identifies a cohort of large, younger farmers who might plant if the forest income is greater than the agricultural income. The analysis indicates that these farmers are likely to have larger farms and may have off-farm income but are also less aware of the permanence of the planting decision. However, this is not a homogeneous group although the farms display common characteristics around lifestyle decisions to optimise their land and time resources.

Policy options

In the context of trying to understand how to achieve an increase in afforestation rates, the analyses summarised here give us an appreciation of the challenges involved in increasing the uptake of afforestation incentive schemes. Drawing from economic theory, a number of potential options to mitigate such challenges can be suggested, as follows.

Providing environmental public goods

There are important public policy drivers for afforestation including carbon sequestration to counter-balance GHG emissions from agriculture. From an environmental economics point of view, the marginal benefit to a farmer from planting is less than the marginal benefit to the state for planting. There is therefore, a rationale for Pigouvian transfers to farmers to motivate them to provide this environmental public good.

Overcoming inertia

For many farmers, negative cultural or attitudinal values are deeply held and can outweigh the greater pecuniary benefits that may be offered by afforestation. Therefore monetary compensation for income foregone may not be sufficient to incentivise the change to a less preferred land use option. An approach to potentially overcome the attitudinal "hurdle" associated with, in the first instance, the consideration of afforestation, is the concept of the "compensating differential" (Carpenter et al. 2015) in the labour economics literature, which refers to the additional income that a worker must be offered as compensation to undertake less desirable tasks.

Scheme design –timing of payment

The long-term nature of the economic return from forestry is contrary to the preference for income now, rather than later. At present initial establishment costs and loss of income (for 15 years) are compensated, however the return on investment arises primarily through harvesting at perhaps 40 years from planting. While in theory the timing of payments does not matter, in reality farmers cannot easily borrow against future income. Bacon (2004) suggested that the State should have an option or right to purchase the timber in a plantation from year 10 at a price that would equate to the final timber value. Similarly, financial incentives by institutional investors could potentially pay farmers a bond for future planting rights, incorporating a greater degree of income front-loading, say in exchange for a share of future harvesting income.

Risk management

Consideration could be given to the establishment of a state insurance scheme for forestry. State provision is justified on the basis of insurance market failures in the forestry sector. The availability of timber insurance in some countries demonstrates that the reduction of transaction costs by the government or by landowner associations is a possibility, and that this can assist the growth of the timber insurance business (Zhang and Stenger 2014). Following devastating losses caused by two winter storms in 1999 and 2009, proposals for legislation and a timber insurance programme have been made in France. However, Brunette and Couture (2008) suggested that governments should not provide direct compensation for forest damage as this would reduce incentives for risk management. They suggested that it is more appropriate for governments to offer aid to landowners who protect their assets through insurance. The question of whether governments might make insurance mandatory for private forest owners, thus reducing risk for insurers and lowering premium prices, is more controversial. So far, no country has adopted this approach (Zhang and Stenger 2014).

Linking afforestation and agricultural land use decisions

Effecting behavioural change can be a complex, time consuming process, particularly if adoption of a practice is voluntary. Vanclay and Lawrence (1995) found that when changes or innovations were unproven, and / or "contrary to accepted farming ways", adoption of new technologies/practices could be lower than anticipated. Vanclay (2004) states that different farmers have "different priorities, different understandings, different values and different ways of working". This is consistent with the research presented in this paper which suggests that due to the underlying heterogeneity of the farming population, a "one rule for all" approach is likely to have limited success and that a more targeted approach, informed by qualitative research, may be necessary to improve the uptake of farm afforestation in future.

The analysis of other farm decisions that are contemporaneous with the planting decision illustrates that the afforestation decision seems to be part of a wider farm management decision and suggests that farmers may be more likely to plant if afforestation is linked to things they want to do on their farm. For example, in the early years of the pooled dataset examined, farmers, who would have generated higher incomes from agriculture than from forestry, were responsible for a large proportion of annual afforestation. This was driven by dairy farmers who wanted to expand their dairy production. In the 1980s, before quotas were ring-fenced, farmers had to buy both the quota and the land to which the quota was attached. In many cases where the land was not close to the home farm, farmers bought and afforested the land in order to acquire the attached dairy quota.

For many years, forest and agricultural subsidies were mutually exclusive. In recent years, changes to agri-environment schemes and direct payments have been favourable towards farm afforestation. However, incentives to date have been independent of other decision-making at farm level, although the recent COFORD (2016) report on land availability recognises the merits of a whole farm incentives approach. Linking forestry and agricultural incentives around actions such as the facilitation of land mobility and succession or the protection of watercourses using riparian buffer zones can provide for "win win" outcomes.

Linking carbon neutrality objectives

There are a number of "win win" methods to reduce or mitigate GHG emissions, such as the displacement of fossil fuels with wood biomass or improvements in the efficiency of food production utilising genetic technologies. However, even with the adoption of the suite of options in the carbon mitigation toolkit, it will be difficult for Ireland to meet its GHG reduction commitments from 2020 onwards. There is increasing policy pressure to explicitly motivate the linkage between expansion activities that generate carbon emissions such as dairy expansion and measures that mitigate these carbon emissions such as afforestation.

In 2015 Teagasc made a pre-budget proposal that linked a reduction in the tax-payable to expanding dairy farmers on the increase in value of their herd if it was offset by afforestation (either on their own land or another farmer's land) (Connolly et al. 2015). This would utilise the stock relief policy lever within the tax code. For the expansion to be carbon neutral, research suggests that one hectare of forest would need to be planted for every 5 additional livestock units (Lanigan and Richards 2014). This incentive of tax reductions associated with increasing stock values through stock relief has already been introduced as an incentive for behavioural change for young farmers and partnerships. It could also be considered for afforestation associated with carbon neutral dairy expansion.

Extension

The role of extension in the context of incentivising afforestation is highlighted by Bell et al. (1994) who report that indirect (extension) as well as direct (financial) incentives can lead to better uptake of forest programmes. An examination of the feasibility of structuring afforestation incentives to coincide with whole farm planning actions incentivising farm re-structuring or greenhouse gas mitigation, could overcome some of the barriers that currently hinder the land use change to forestry.

Requirement to re-forest (irreversibility)

Given farmers' preferences to farm and their concern about inter-generational attachment to the land, the permanence of the decision to afforest is a significant barrier to planting (McDonagh et al. 2010). This barrier is compounded by the high level of awareness of the permanence of the decision among farmers surveyed (Ryan and O'Donoghue 2016). The attachment to land in Ireland is evidenced by the fact that on average only half a percent of total land area changes hands in any given year (Ganly 2009). Policy makers are increasingly looking to behavioural economics for solutions to overcome barriers associated with other long-term investments, such as the decline in personal pensions (Tapia and Yermo 2007). In recent years, the UK introduced voluntary opt out pension clauses and found that auto enrolment pension schemes (with the right to opt out) have much higher participation rates (Pensions Commission 2004). The Pensions Commission also find that a high level of inertia prevails after long term decisions are made. In general, opt out rates in the UK are in the region of 1 in 10 in recent years (O'Loughlin 2015).

Drawing lessons from behavioural economics applied to pensions, there are merits to considering the possibility of land use reversion, as the barrier to planting in the first instance could be lowered. There is already an element of discretion allowed in relation to reforestation and it is a matter of policy how this is implemented.

However given the high cost associated with forest removal, there are likely to be strong disincentives to reverting the land to agricultural use. This cost builds on natural inertia which means that once a land use decision is made, there is a relatively low chance of change in any case. As a corollary to this, increased forestry-related land use change, could reduce the socio-cultural barriers to afforestation, in the same way that initial agri-environmental scheme participation in the 1990s reduced the general antipathy towards agri-environmental programmes, significantly changing attitudes and participation levels (Murphy et al. 2014).

Establishment costs of second and subsequent rotations

Providing for re-establishment costs for second and subsequent rotations would widen the financial gap between reforestation and re-converting the land to agriculture and reduce concerns in relation to the cost of reforestation.

Differential land availability

An additional 510,000 ha of afforestation would be required to achieve the 18% forest cover target by mid-century (COFORD 2016). The analyses summarised in this paper show that soil type is an important physical driver of both the economic return to afforestation and the agricultural opportunity cost of farm afforestation. Ryan and O'Donoghue (2016) further report that fibre and sequestration demands can be optimised on land which is not necessarily economically attractive for agriculture. Farrelly and Gallagher (2016) identified a total of 423,000 ha of wet grassland and unimproved land that occurs on the margins of productive agricultural land and in marginal agricultural areas that is suitable for afforestation. However, this research shows that under the current policy incentives, a large proportion of farmers are not prepared to consider afforestation.

In light of the conflicting demands on land use and common objectives around the provision of ecosystem services such as carbon sequestration, fibre for timber processing and renewal energy and the provision of biodiversity and good quality air and water, there is merit in developing long term integrated land use policies. The concept of Functional Land Management (Schulte et al. 2014) recognises the differential capacity of different soils and environmental conditions to sustainably intensify land-based production of food, fibre and ecosystem services. However, new land use policies and objectives should aim to span multiple Common Agricultural Policy (CAP) periods. For example, the initial afforestation "hurdle" could be reduced if farmers were confident that planting land would not disadvantage them in relation to future agricultural schemes i.e. if a commitment was given in relation to the continuity of the social benefits generated by farmers who plant.

References

Bacon, P. and Associates. 2004. *A Review and Appraisal of Ireland's Forestry Development Strategy*. Published by Stationery Office, Dublin.

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

Bell, C.D., Roberts, R.K., English, B.C. and Park, W.M.J. 1994. A logit analysis of participation in Tennessee's forest stewardship program. *Journal of Agricultural and Applied Economics* 26: 463–472.

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

Brunette M. and Couture S. 2008. Public compensation for windstorm damage reduces incentives for risk management investments. *Forest Policy and Economics* 10: 491–499.

Carpenter, J., Matthews, P.H. and Robbett, A. 2015 Compensating Differentials in Experimental Labor Markets. IZA Discussion Paper No. 8820. http://ftp.iza.org/dp8820.pdf [Accessed September 2016].

COFORD. 2016. Land Availability for Afforestation – Exploring opportunities for expanding Ireland's forest resource. COFORD Land Availability Working Group. COFORD, Dublin.

Connolly, K. 2015. Teagasc pre-budget submission to the Agri-Taxation working group. Teagasc. 24th July 2015.

Cummine, A. 2000. *Plantation Insurance: an Introduction*. Dickson, ACT, Australia: Australian Forest Growers. http://www.afg.asn.au/images/stories/PDF/Publications/Conference_Papers/Earlier_Conferences/Plantation_insurance_an_introduction.pdf [Accessed September 2016].

DAFF. 1996. *Growing for the Future – A Strategic Plan for the Development of the Forestry Sector in Ireland*. Department of Agriculture, Food and Forestry. The Stationery Office, Government Publications Sales Office, Molesworth Street, Dublin.

DAFF. 2010. *Food Harvest 2020 – A Vision for Irish Agri-Food and Fisheries*. Department of Agriculture, Fisheries and Food, Dublin.

DAFM. 2014. *Forest Policy Review –Forests Products and People*. Department of Agriculture, Food and Marine, Dublin.

DAFM. 2015. *Food Wise 2025*. Department of Agriculture, Food and Marine, Dublin.

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

Duesberg, S., Ní Dhubháin, A. and O'Connor, D. 2014. Assessing policy tools for encouraging farm afforestation in Ireland. *Land Use Policy* 38:194–203 .

Edwards-Jones, G. 2006. Modelling farmers' decision-making: concepts, progress and challenges. *Animal Science* 82: 783–790.

EPA. 2015. Environmental Protection Agency. Available at https://www.epa.ie/irelandsenvironment/environmentalindicators/#top [Accessed March 2016].

EUCO. 2014. The 2014 European Council Agreement on Climate and Energy Targets for 2030. European Council (EUCO 169/14).

Eurostat. 2013. Agriculture, forestry and fishery statistics 2013. http://ec.europa.eu/eurostat/documents/3930297/5968754/KS-FK-13-001-EN.PDF/ef39caf7-60b9-4ab3-b9dc-3175b15feaa6 [Accessed September 2016].

FAO. 2009. *How to Feed the World in 2050*. Food and Agriculture Organisation of the United Nations. Available at http://www.fao.org/fileadmin/templates/wsfs/docs/expert_paper/ How_to_Feed the_World in_2050.pdf [Accessed March 2016].

Farrelly, N. and Gallagher, G. 2016. Potential availability of land for forestry. *TResearch*. April 2016. Teagasc, Oak Park.

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

Frawley, J. and Leavy, A. 2001. Farm forestry: land availability, take-up rates and economics, Project report No. 4256, RERC, Teagasc.

Ganly, R.J. 2009. *Land Market Review –Spring 2009*. Knight Frank, Dublin.

Hendrick, E. and Black, K. 2009. Climate change and Irish forestry. *COFORD Connects Environment No. 9*. COFORD, Dublin.

Hennessy, T. and Moran, B. 2015. *Teagasc National Farm Survey – Preliminary Results 2014*. Teagasc, Oak Park, Carlow.

Howley, P., Buckley, C., O'Donoghue and Ryan, M. 2015. Explaining the economic "irrationality" of farmers' land use behaviour: The role of productivist attitudes and non-pecuniary benefits. *Ecological Economics* 109: 186–193.

Kanowski, P. 2010. Policies to enhance the provision of ecosystem goods and services from plantation forests. In *Ecosystem Goods and Services from Plantation Forests*. Eds. Bauhus, J., Meer, P.J.v.d. and Kanninen, M.,. Earthscan Publications Ltd, London, pp. 171–204.

Key, N. and Roberts, M.J. 2009. Non-pecuniary benefits to farming: implications for supply response to decoupled payments. *American Journal of Agricultural Economics* 91: 1–18.

Lanigan, G. and Richards, K. 2014. Policy Challenges for Reducing GHG Emissions. Presented at Teagasc Environment Conference 2014. Available at http://www.teagasc.ie/publications/2014/3366/Karl-Richards-Gary-Lanigan-Env-Conf.pdf [Accessed September 2016].

Lawrence, A. and Dandy, N. 2014. Private landowners' approaches to planting and managing forests in the UK: what's the evidence? *Land Use Policy* (36): 351–360.

Matthews A. 2015. Carbon reduction clock is ticking for farming. Farming Independent. 23/9/2015. Retrieved from http://www.independent.ie/business/farming/carbon-reduction-clock-is-ticking-for-farming-31546417.html [Accessed September 2016].

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

McCormack, M. and O'Donoghue, C. 2014. Policy incentives as behavioural drivers of beef enterprises in Ireland: where are the kinks? Paper presented at EAAE 2014 Congress. 26-29th August 2014. Ljubljana, Slovenia.

McDonagh, J., Farrell, M., Mahon, M. and Ryan, M. 2010. New opportunities and cautionary steps? Farmers, forestry and rural development in Ireland. *European Countryside* 2: 236–251.

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

Mindspace. 2010. Farmers Research Study. Report to Forestry Commission Scotland. pp 77.

Murphy, G., O'Donoghue, C., Hynes, S. and Murphy, E. 2014. Modelling the participation decision in agri-environmental schemes. Paper presented to European Association of Agricultural Economists Congress, Ljubljana, Slovenia, 26–29th August 2014. Available at http://purl.umn.edu/183069 [Accessed November 2016].

NESC. 2013. *Ireland and the Climate Change Challenge: Connecting "How Much" with "How To" National Economic and Social Council*. Report no. 4. Retrieved from http://files.nesc.ie/nesc_reports/en/Ireland%20and%20the%20Climate%20Change%20Challenge_Connecting%20How%20Much%20with%20How%20To_Exeuctive%20Summary.pdf [Accessed November 2016].

Ní Dhubháin, Á. and Gardiner, J. 1994. Farmers' attitudes to forestry. *Irish Forestry* 5: 21–26.

Nijnik, M., Bizikova, L. 2008. Responding to the Kyoto Protocol through forestry: a comparison of opportunities for several countries in Europe. *Forest Policy and Economics* 10: 257–269.

OCarroll, N. 2004. *Forestry in Ireland – a Concise History*. COFORD, Dublin.

O Donoghue, E.J. and Whitaker, J.B. 2010. Do direct payments distort producers' decisions? An examination of the farm security and rural investment act of 2002. *Applied Economic Perspectives and Policy* 32: 170–193.

O'Loughlin, D. 2015. Inertia drives success, but no room for complacency. Financial Adviser. http://www.ftadviser.com/2015/04/07/pensions/personal-pensions/inertia-drives-success-but-no-room-for-complacency-spFKsaYjjxuORYXHhClZ3J/article.html [Accessed November 2015].

Pensions Commission. 2004. Pensions Commission – the Institute for Government. Retrieved from http://www.instituteforgovernment.org.uk/sites/default/files/pension_reform.pdf [Accessed November 2016].

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

Ryan, M. 2016. Economics of farm afforestation in Ireland. Unpublished PhD thesis. Discipline of Economics. Hardiman Library. NUI, Galway.

Ryan, M. and O'Donoghue, C. 2016. Heterogeneous economic and behavioural drivers of the farm afforestation decision. Paper presented at BIOECON 2016. Cambridge, UK. 14–16th September.

Ryan, M., Buckley, C., Dillon, E.J., Donnellan, T., Hanrahan, K., Hennessy, T., Moran, B. and Kelly, E. 2015a. The most economically efficient farms produce lowest ghg emissions per kg of product. *Eurochoices* 14: DOI 10.1111/1746-692X.12078.

Ryan, M., O'Donoghue, C. Upton, V. 2015b. *Land Use Change from Agriculture to Forestry: a Structural Model of the Income and Leisure Choices of Farmers*. International Association of Agricultural Economists Conference, 9th–14th August 2015, Milan, Italy. Available at http://purl.umn.edu/212285 [Accessed November 2016].

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

Ryan, M., Kinsella, A. and Cushion, M. 2008. *An Assessment of Farmer Intentions to Plant a Forest*. Agricultural Research Forum. Teagasc. Retrieved from http://www.agresearchforum.com/publicationsarf/2008/proceedings2008.pdf [Accessed November 2016].

Schelhaas, M.J. 2008. Impacts of Natural Disturbances on the Development of European Forest Resources: application of Model Approaches from Tree and Stand Levels to Large-Scale Scenarios. Thesis presented to Faculty of Forest Sciences, University of Joensuu (Dissertationes Forestales 56). Retrieved from http://www.metla.eu/dissertationes/df56.pdf [Accessed November 2016].

Schulte, R.P.O, Creamer, R.E., Donnellan, T., Farrelly, N., O'Donoghue, C., O hUallachain, D. 2014. Functional land management: A framework for managing soil-based ecosystem services for the sustainable intensification of agriculture. *Environmental Science and Policy* 38: 45–58.

Tapia, W. and Yermo, J. 2007. *Implications of Behavioural Economics for Mandatory Individual Account Pension Systems*. OECD Working Papers on Insurance and Private Pensions, No. 11, OECD Publishing. doi:10.1787/103002825851.

Schulte, R.P.O., Donnellan, T., Black, K.G., Crosson, P., Farrelly, N., R.M. Fealy, R.M., Finnan, J., Lanigan, G., O'Brien, D., O'Kiely, P., Shalloo, L. and O'Mara, F.

2013. *Carbon Neutrality as a Horizon Point for Irish Agriculture – a Qualitative Appraisal of Potential Pathways to 2050*. A report by the Teagasc Working Group on Greenhouse Gas Emissions. Teagasc. Oak Park, Carlow.

UNFCCC. 2016. Report of the Conference of the Parties on its twenty-first session. United Nations Framework Convention on Climate Change. Available at http://unfccc.int/resource/docs/2015/cop21/eng/10.pdf [Accessed March 2016].

Upton, V., Ryan, M., Farrelly, N. and O'Donoghue, C. 2013. The potential economic returns of converting agricultural land to forestry: an analysis of system and soil effects from 1995 to 2009. *Irish Forestry* 70: 61–74.

Vanclay, F. 2004. School principles for agricultural extension to assist in the promotion of natural resource management. *Australian Journal of Experimental Agriculture* 44, pp. 213–222.

Vanclay, F. 1992. The social context of farmers' adoption of environmentally sound farming practices. In Agriculture, Environment and Society. Eds. Lawrence, G., Vanclay, F., Furze B., Macmillan, Melbourne, pp. 94–121.

Vanclay, F. and Lawrence, G. 1995 *The Environmental Imperative: Eco-Social Concerns for Australian Agriculture*. Rockhampton, Queensland: Queensland University Press.

Watkins, C., Williams, D. and Lloyd, T. 1996. Constraints on farm wood-land planting in England: a study of Nottinghamshire farmers. *Forestry* 2: 167–176.

Zhang, D. and Stenger, A. 2014. Timber insurance: perspectives from a legal case and a preliminary review of practices throughout the world. *New Zealand Journal of Forestry Science* 44 (Supplement 1): S9.

A comparison of biomass production and machine system productivity using three harvesting methods in a conifer first thinning

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Abstract

A thinning trial took place in a 19-year-old Sitka spruce (*Picea sitchensis* (Bong.) Carr) plantation in the south east of Ireland where three methods of harvesting were performed using the same harvester and forwarder machine system: cut to length harvesting (CTL), integrated harvesting (INT), and whole tree harvesting (WT). The objectives of the trial were to evaluate the log volume and biomass mobilised using each method, the productivity of the machines, and quality parameters of the biomass as a fuel. Using the CTL method, 56.5 m^3 ha^{-1} of pulpwood and 6.4 m^3 ha^{-1} of small sawlog were harvested. This equated to 23.6 odt ha^{-1} of roundwood material. A greater amount of biomass was mobilised using the INT and WT harvesting methods than the CTL method. On average, compared to the CTL method, 81.8% more biomass was mobilised by the INT method and 93.6% more biomass was removed by the WT method. Wood fuel supply chain (harvesting, forwarding, and chipping) cost to the forest roadside was highest for CTL, and was 23% lower for INT, and 33% lower for WT. The results suggest that the potential biomass mobilisation from first thinnings may be greater than current estimates suggest, while harvesting costs may be further reduced by employing specialised methods. However, the trial was confined to one site, and therefore as the results are site specific they need to be interpreted with caution.

Keywords: *Thinning, biomass, whole tree, integrated harvesting, cut to length.*

Introduction

In Ireland, the latest National Forest Inventory (Forest Service 2015) shows forest cover is currently at 10.5%, of which 53% is publicly owned, with 47% in private ownership. Privately-owned forest comprises c. 72% grant-aided, and 28% non-grant aided. Grant-aided forests are a direct outcome of the support structures put in place over the last 30 years by the Irish government with the aim of increasing forest cover. Reflecting these measures, there has been an increase in planting, such that 84% of grant-aided private forests in Ireland is less than 20 years of age. In total, Sitka spruce (*Picea sitchensis* (Bong.) Carr.) comprises 52.5% of the forest area in Ireland, and 60% of the private grant-aided forest area.

In Ireland, approx. 95% of harvesting employs a cut to length (CTL) method (Karjalainen et al. 2001), but in first thinning, with small tree sizes, these systems may not be cost-effective due to high machine costs and low value markets. Since many private

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landowners have had little prior experience in forestry, and few have forest plantations older than about 30 years, there is a need for thinning operations to be profitable in the short term to encourage owners to thin their forests. Mobilising biomass from such plantations, using cost-effective methods of thinning, is consequently a topical and active research area in Ireland.

It is estimated that due to EU Directives and national policies, the demand for forest based biomass for energy in Ireland will be 3,084,000 m^3 per annum by the year 2020 (CRDG 2011) However, it is estimated that only 1,453,000 m^3 of forest biomass will be available for the bioenergy market from current sources (Phillips 2011). This forecast of supply, while it includes stemwood to tip, does not include branch biomass. As such, there is potential for harvesting methods other than conventional cut-to-length systems to bridge the gap between the supply and potential demand for forest biomass.

The objectives of this study were to compare alternative methods of harvesting in a first thinning and to: 1) quantify the harvestable and mobilised roundwood (merchantable stem cross cut into lengths) and biomass material available (that can be mobilised for use as wood fuel); 2) estimate machine system productivity; 3) estimate the quality of the biomass wood fuel available; and 4) identify the supply chain variables affecting productivity. Harvestable roundwood volume is typically estimated from measurements of standing trees and a harvesting reduction factor is used to convert this to material that can be mobilised. Biomass harvesting implies that stemwood less than 7 cm top diameter and branchwood is also recovered.

The machine costs estimated in this study include only harvesting costs for the operations carried out on site, and exclude business overheads, fleet management costs, or site relocation costs.

Materials and methods

Study layout and treatments

The study area was 0.86 ha within a 19-year-old Sitka spruce monoculture, planted on mounds with six lines of trees between drains, at Dungarvan, Co. Kilkenny (52° 33' 42" N, 7° 04' 00" E). Stocking was 2,483 trees ha^{-1}, mean DBH was 15 cm, and mean top height was 12.8 m. The study area consisted of 54 tree rows divided into nine plots: three plots per harvesting method; where each 12 m wide plot was the working width for a machine pass, located between two drains and was approximately 80 m in length. The thinning prescribed for the site was a one line in six systematic thinning with selection in between, removing approximately 40% of the stems and 30% of the basal area.

The machine system used in the trial was a John Deere 1070D harvester fitted with a John Deere 752 CTL harvester head; a John Deere 810D forwarder, and; a Komptech Chippo 5010 Cd chipper mounted on a MAN truck and powered by its engine. Harvesting was carried out in October 2014 and forwarding in November 2014. Chipping took place in April and June 2015. The same experienced operators were used for all harvesting methods. The three harvesting methods trialled are detailed below.

Harvesting Method 1: Cut to length harvesting, CTL (See Figure 2)
The harvester processed two assortments of roundwood: small sawlog (3.1 m length, 14 cm minimum small-end diameter) and pulp logs (3 m length, 7 cm minimum small-end diameter). Roundwood was placed off the extraction rack in bunches while tree tops and branches were placed in the rack for use as a brash mat. Logs were forwarded to the forest roadside, with the sawlog and pulp being stacked separately. The pulp roundwood was retained for seven months to season and was then chipped at roadside for use as a fuel, while the small sawlog was removed to a sawmill shortly after harvesting.

Harvesting Method 2: Integrated harvesting, INT (See Figure 3)
The harvester processed small sawlogs only, which were placed in bunches off the rack. The remainder, including stem wood categorised as pulpwood category, was also set aside off the rack as a wood fuel. No brash mat was used, although some branches that were delimbed while processing the small sawlog remained in the rack. The small sawlog and wood fuel were forwarded to the roadside and stacked separately. Small sawlog was removed shortly after harvesting and the wood fuel was stored for nine months before being chipped at the roadside.

Harvesting Method 3: Whole tree harvesting, WT (See Figure 4)
The harvester did not process any roundwood; instead the whole tree was cut into two biomass lengths to facilitate forwarding and placed perpendicular to the extraction rack. No brash mat was used. These biomass tree sections were stacked at roadside for nine months and then chipped.

Data Collection

Pre-thinning standing measurements
Prior to harvesting, plot areas were surveyed, and boundary trees were marked with paint at ground level so that stumps could be identified after harvesting. Location and DBH of every tree in each plot was recorded, as were all missing or dead trees.

Post-thinning standing measurements
Every thinned tree was identified and used to calculate the proportion, basal area, and volume of the trees removed, and to describe stocking and basal area per hectare of the maincrop remaining after thinning. The standing volumes were estimated using the full tariff procedure (Matthews and Mackie 2006). The stand tariff number was calculated using felled sample trees, as outlined below.

Sample tree measurements

Data used for the quantification of volume and biomass harvested were gathered from the measurement and weighing of 15 trees on the site, which were used to develop a site specific biomass equation and to estimate the basic density of the roundwood. Trees were selected to represent the range of the thinned DBH distribution and included the smallest and largest DBH harvested (9 and 21 cm, respectively) with at least one sample from each 2 cm diameter. The fifteen trees were felled by chainsaw, and DBH, stump height, total height (including stump height), height at 7 cm diameter of the stem (merchantable stem), and midpoint diameter of the merchantable stem were measured. Each tree was then partitioned into small sawlogs, pulp logs, branches, and tops. The mid diameter and length of each log was measured and the log weighed. Three discs were cut from each log (midpoint, and half way from the midpoint to each end of the log) for moisture content and density determination. The branches and tops were weighed, chipped on site with a Linddana TP200 chipper, and sampled for moisture content. Moisture content was determined by oven drying at 105 °C for 48 hours. Volume was determined by submersion in a water bath and density was calculated as dry mass divided by volume. The relationship between basal area and dry matter (biomass) was then determined.

Quantification of harvested material

The biomass harvested, defined as the total harvested biomass contained in a thinned tree, was estimated by inputting the DBH for each tree in the plot into the biomass equation. For the woodfuel assortments, the total weight and moisture content of the stacks were used to estimate the dry weight of the stack. For roundwood assortments length and mid diameter of each log was measured. The total volume was converted to dry weight using the basic density as estimated from the sample trees. The biomass mobilised, defined as the biomass that was removed to roadside was estimated from the sum of the oven dry weights of the products from each method.

Quantification of mobilised material and wood fuel quality

The underlying data for the quantification of mobilised biomass and wood fuel quality parameters were gathered from weights and samples taken during the chipping of each stack of wood. Each stack of wood was chipped separately into a walking floor truck and weighed on a weighbridge. Five random fifty litre samples of woodchip were taken from each wood fuel assortment during chipping operations. Moisture content, bulk density, particle size distribution, calorific value and ash content were determined from the woodchip samples. These quality parameters were assessed using European solid biofuel standards, as per Coates et al. (2014). Moisture content was determined using the oven dry method at 105 °C for 48 hours, according to EN 14774-3:2009, and expressed as a percentage of total weight. Bulk density, expressed in kilograms per cubic metre, was estimated according to EN 15103:2009. Particle size distribution was determined using an oscillating sieve method as per EN 15149-1:2010 and classified according to the new

ISO standard, ISO/DIS 17225-1. Ash content, expressed as percentage dry weight, was determined using a Carbolite muffle furnace at 550 °C, according to EN 14775:2009. Calorific value, expressed in Giga joules per tonne, was determined, using a Parr 5500 oxygen bomb calorimeter, according to EN 14918:2009.

Machine operations measurements

Time-and-motion studies were performed on the harvester, forwarder and chipper. The resolution of the harvester study was at the plot level. The forwarder was studied at the cycle level, where a cycle was defined as the extraction of one load to the roadside.

Table 1: *Machine rate calculations for the machines used in the trial.*

Rate	Unit	Harvester: John Deere 1070D	Forwarder: John Deere 810D	Chipper: Komptech Chippo 5010 CD
Machine price:	€	365,000[a]	235,000[a]	610,000[b]
Machine power:	kW	136	86	397
Salvage value:	€	73,000[c]	47,000[c]	122,000[c]
Economic life:	yrs	8[d]	7[e]	8[f]
Annual scheduled machine hours (SMH):	h a^{-1}	2,000	2,000	2,000
Utilisation percentage:	%	65[g]	65[g]	40[g]
Annual productive machine hours (PMH):	h yr^{-1}	1,300	1,300	800
Depreciation:	€ yr^{-1}	37,922	27,246	61,000
Interest:	€ yr^{-1}	20,227[h]	13,143[h]	33,703[h]
Insurance:	€ yr^{-1}	9,518[h]	6,185[h]	15,860[h]
Maintenance and repair:	€ PMH^{-1}	29.2[i]	16.8[i]	76.3[i]
Fuel:	€ PMH^{-1}	8.6[j]	5.6[j]	26.0[j]
Lubrication:	€ PMH^{-1}	3.0[k]	2.0[k]	9.1[k]
Labour incl. benefits:	€ PMH^{-1}	32.2[l]	32.2[l]	52.3[l]
Overheads per SMH:	€ SMH^{-1}	4.1[m]	3.0[m]	6.0[m]
Profit per SMH:	€ SMH^{-1}	7.7[n]	5.7[n]	11.4[n]
Total rate per SMH:	€ SMH^{-1}	93.0	68.7	138.2
Total rate per PMH:	€ PMH^{-1}	143.1	105.7	345.5

[a]John Deere agent for Ireland: John Deere Forestry Ire Ltd, personal communication 18th August 2015. Note: the prices quoted are for the equivalent new series of John Deere machine, i.e. 1070E and 810E, as the D line is now superseded. [b]Komptech agent for Ireland: Environmental Technology Resources Ltd, personal communication 19th August 2015. [c]Salvage value set as 20% of the purchase price at the end of economic life. ([d]Weise et al. 2009. [e]Lyons 2015). [f]Prada et al. (2015). [g]Coates et al. (2014). [h]Interest rate set at 8.5 %, Insurance rate set at 4 %. [i]Repair and maintenance set as a percentage of depreciation per year as per Ackerman 2014: (Harvester 100 %, Forwarder 80 %, Chipper 100 %). [j]Fuel consumption calculated as a function of engine size as per Ackerman 2014, and fuel cost per litre as per IFA (2015). [k]Estimated as 35% of the fuel cost, as per Murphy (2010). [l]Labour cost set at €15.5 per SMH, and benefits set at 35 %. Labour rate for the chipper appears higher per PMH as the utilisation percentage for the chipper is lower than the other machines. [m]Overheads set as 5 %. Profit was set at 9%.

Chipping operations were recorded as the productive time required processing each stack.

Only productive time recorded in the field was used for machine productivity calculations, as defined by Magagnotti and Spinelli (2012). The cost of running each machine per hour was estimated per productive machine hour (PMH) using the method set out by Miyata (1980) and Ackerman (2014).

Influence of moisture content on fuel quantification (by volume, weight and energy)

Moisture content affects the net energy content of woodfuel, and therefore should be reduced through air drying in order to optimise the supply chain (Hakkila 2004). Moisture content also affects weight, and so presents difficulties when trying to quantify and trade wood fuels. The following equations were used to quantify the wood fuel products on-site according to a range of moisture contents in terms of weight, volume, and energy:

$$Weight\ (t) = 100 \times \left(\frac{odt}{100 - MC}\right) \qquad [1]$$

$$Volume\ (m^3) = \frac{Weight\ (t) \times (1 - \left(\frac{MC}{100}\right)}{Basic\ density\ (t\ m^{-3})} \qquad [2]$$

$$NCV_{db} = GCV_{db} - 212.2 \times H - 0.8 \times O + N \qquad \text{(EN ISO 17225-1: 2014)} \quad [3]$$

$$NCV_{ar} = NCV_{db} \times \left(\frac{100 - MC}{100}\right) - 0.02443 \times MC \qquad \text{(EN ISO 17225-1: 2014)} \quad [4]$$

$$GJ\ ha^{-1} = NCV_{ar} \times Weight\ ha^{-1}(t) \qquad [5]$$

where:

MC = moisture content expressed as a percentage of total weight;

GCV_{db} = gross calorific value for dry matter at a constant pressure in joules per gram;

NCV_{db} = net calorific value for dry matter at a constant pressure in joules per gram;

H = is the hydrogen content, in percentage by mass, of the moisture-free (dry) wood fuel, given as 6.3% for a raw material of roundwood, and 6.0% for a raw material that includes branches and needles (EN ISO 17225-1: 2014);

O = the oxygen content, in percentage by mass, of the moisture-free wood fuel, given as 42% for a raw material of roundwood, and 40% for a raw material that includes branches and needles (EN ISO 17225-1: 2014);

N = the nitrogen content, in percentage by mass, of the moisture-free wood fuel, given as 0.1% for a raw material of roundwood, and 0.5% for a raw material that includes branches and needles (EN ISO 17225-1: 2014).

Results

Sample tree measurements

The sample tree dry weight ranged from 8.1 kg (0.0072 m^2 BA) to 137.3 kg (0.0366 m^2 BA). A straight line equation was found to give a good model fit for dry matter versus basal area (Figure 1). The fit had an R-squared value of 94.2% (R-squared adjusted was 93.7%). Basic density of roundwood products was measured as being 382 kg m^{-3}. The equation to predict total aboveground biomass from basal area on the site was:

$$\textit{Total above ground dry matter per tree}\ (\text{kg}) = -10.28 + (3633 \times \textit{Basal area})\ (\text{m}^2) \quad [6]$$

Silvicultural treatment

It was important to demonstrate that differences in the quantities of biomass being mobilised could be attributed to harvesting method rather than differences in the number or size of trees thinned between plots. Table 2 details the silvicultural treatment using each of the methods. The percentages of trees removed per ha^{-1} was: CTL, 44%; INT, 46%; and WT, 44%. The percentages of basal area removed ha^{-1} was: CTL: 36% (15 m^2), INT: 36% (16 m^2), and WT: 35% (15 m^2). The quadratic mean DBH (QMDBH) before thinning was 15 cm for all treatments, mean DBH of the trees removed was 13 cm for all treatments, and the mean DBH of the main crop was 16 cm for all treatments.

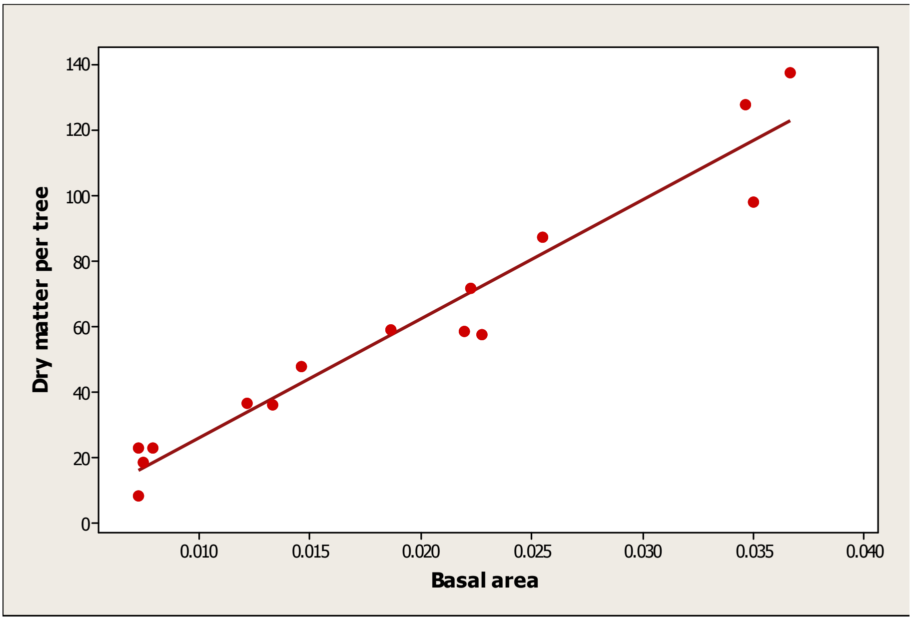

Figure 1: *Scatterplot of aboveground biomass per tree (kg) vs. basal area (m^2).*

Table 2: *Stocking, DBH, basal area and volume assessment of the harvesting methods, expressed per net productive hectare.*

Method	Pre thin				Thinning						Main crop			
	Trees ha^{-1}	QMDBH (cm)	Basal area (m^2)	Merch. vol. (m^3)	Trees ha^{-1}	% trees removed	QMDBH (cm)	Basal area (m^2)	% basal area removed	Merch. vol. (m^3)	Trees ha^{-1}	QMDBH (cm)	Basal area (m^2)	Merch. vol. (m^3)
CTL	2,466	15	42	192	1,085	44	13	15	36	65	1,381	16	27	137
INT	2,517	15	44	204	1,148	46	13	16	36	69	1,370	16	28	135
WT	2,507	15	42	197	1,097	44	13	15	35	64	1,409	16	28	133

Table 3: *Harvested and mobilised biomass, and assortments produced from each harvesting method. Standard deviations in parenthesis. Merchantable volume/odt refers to volume to 7 cm top diameter. Harvested biomass refers to the total aboveground biomass contained in the harvested trees. Mobilised biomass refers to the biomass that was removed from the site.*

Treatment	Thinned merchantable vol.	Thinned merchantable vol.	Harvested biomass	Mobilised biomass	Assortments		
					Small sawlog	Pulp logs	Wood fuel
	(m^3 ha^{-1})	(odt ha^{-1})	(odt ha^{-1})	(odt ha^{-1})	(m^3 ha^{-1})	(m^3 ha^{-1})	(odt ha^{-1})
CTL	65 (7.6)	25 (2.9)	46 (2.1)	24	6 (1.8)	57 (3.7)	
INT	69 (0.9)	26 (0.3)	49 (0.5)	43	7 (1.7)	-	41
WT	64 (1.8)	25 (0.7)	46 (1.3)	46	-	-	46

Figure 2: *Thinning method 1: Cut to length (CTL) harvesting. Note the brash mat remaining in the rack and the roundwood on the left hand side. The stack displays the products harvested (small sawlog on the left, pulp logs on the right) from 0.30 ha using this method.*

Figure 3: *Thinning method 2: Integrated (INT) harvesting. Note that there is little brash left in the rack. The small sawlog and woodfuels assortments can be seen placed to each side. The stack displays the products harvested (woodfuel on the left, small sawlog on the right) from 0.28 ha using this method*.

Figure 4: *Thinning method 3: Whole tree (WT) harvesting. Note the absence of a brash mat in the rack. The wood fuel assortment can be seen bunched to the side. The stack displays the wood fuel harvested from 0.28 ha using this method.*

Quantification of biomass and assortment classes

The estimated quantity of biomass mobilised in the trial is shown in Table 3. In the CTL plots, an average 57 m^3 ha^{-1} of pulpwood and 6 m^3 per ha of small sawlog was mobilised. This equates to 24 odt ha^{-1} of roundwood material: the mean roundwood basic density was 382 kg m^{-3}. A greater amount of biomass was mobilised using the INT and WT harvesting methods. On average, a total of 43 odt ha^{-1} (41 odt of biomass, 7 m^3 of small sawlog) was harvested using the INT method, and 46 odt ha^{-1} using the WT method.

If the WT method indicated the potential maximum removal of biomass then the INT method removed 6% less harvested biomass due to delimbing and cutting of small sawlog to length, while the CTL method left behind 48% of harvested biomass, due to delimbing, cutting to length and discarding the stem above 7 cm diameter.

A point to note is that the small sawlog volume mobilised from both the CTL and INT plots was very similar (6.5 m^3 in the INT, 6.4 m^3 in the CTL), indicating that placed the novel INT method did not affect the operator's ability to identify small sawlog in the trees.

Wood fuel quality

The wood fuel quality parameters for products from each harvesting methods are listed in Table 4. At harvesting, CTL roundwood moisture content was 62% and the wood fuel assortments were 59%. Woodfuel moisture contents at time of chipping (seven months later for the CTL assortment, nine months later for the INT and WT wood fuel) was 56% for the CTL roundwood, 59% for the INT wood fuel, and 55% for the WT wood fuel, indicating that there was little natural drying of the material on site over the storage period (October to April/June). Ash content values, expressed as a percentage of dry weight, were as expected, with the CTL roundwood chip having a 0.5% mean ash content with low variation, and the WT and INT

Table 4: *Quality parameters of the wood fuel assortments. Standard deviation in parenthesis.*

Treatment	**CTL**	**INT**	**WT**
Raw material of wood chip	Roundwood, free of branchwood	Small diameter stemwood with branches	Whole stem and branches
Quality Parameters			
Woodchip bulk density, db (kg m^{-3})	159 (8)	171 (6)	164 (4)
Moisture content,% total wt.	55.9 (2.6)	58.8 (1.6)	55.1 (2.7)
Ash content,% db	0.50 (0.11)	2.37 (1.65)	1.37 (0.76)
GCV db (MJ kg^{-1})	19.8 (0.02)	19.7 (0.09)	19.8 (0.12)
NCV ar (GJ $tonne^{-1}$)	6.8	6.1	7.0
Particle size classification: ISO F	F06	F20	F20
Particle size classification: ISO P	P31 medium	P31 medium	45 large

wood fuel having a higher mean ash content of 1.4% to 2.4% and a much higher variability probably related to the higher bark and needle content. Gross calorific value, dry basis, (GCV, db) was the same across all treatments at 19.8 GJ tonne^{-1}. The Net Calorific Value, as received (NCV, ar) describes the energy content net of that energy lost evaporating the moisture contained in the wood fuel at the time of measurement. Therefore, this varied due to different moisture contents between woodchip produced by the three methods. Particle size was classified according to ISO 17225 and notably all treatments failed to classify to the older EN 15149-1 or EN 15149-4 standards. CTL roundwood chip had fewest fine particles (passing through a sieve with 3.15 mm apertures) contributing less than 6% of the total mass (F06). The fines fractions of the INT and WT wood chip were both F20, meaning that 20% by mass was less than 3.15 mm. The CTL and INT wood chip classified as P 31 medium, meaning that over 60% by mass of woodchip was between 3.15 mm and 31.5 mm in length, that less than 6% of the material is over 45 mm, less than 3% of the material is over 100 mm, and that all particles are less than 200 mm. The WT wood chip classified as P45 large due to presence of particles longer than 200 mm.

Machine productivity and cost

The machine productivity and cost for the system operating under each of the harvesting methods is shown in Table 5. The harvester operation times for the CTL and INT methods were similar: at 9.2 and 9.5 PMH ha^{-1} respectively, and less for the WT method, at 8.1 PMH ha^{-1}. The longer time needed to carry out the CTL and INT operations was mostly as a result of the extra time required to identify small sawlog. The one-way extraction distance during the trial was an average of 371 m (min. 317 m, max. 425 m). The forwarder operation time was estimated as 8.9 PMH ha^{-1} for the WT, and 9.3 PMH ha^{-1} for the INT method. The forwarder time was substantially less in the CTL method, at 5.7 PMH ha^{-1}, due mainly to the lower amount of material mobilised. The harvester cost was estimated as €1,321 ha^{-1} using the CTL method, €1,355 ha^{-1} using the INT method, and €1,159 ha^{-1} using the WT method. Forwarding costs were estimated as €602 ha^{-1} using the CTL method, €944 ha^{-1} using the INT method, and €987 ha^{-1} using the WT method.

Table 5 also shows the productivity of the chipper in oven dry tonnes per productive machine hour. The results are similar for all assortments. The CTL roundwood was chipped at a rate of 23.3 odt PMH^{-1}. The INT wood fuel and WT wood fuel assortments were chipped at a rate of 20 odt PMH^{-1}. Consequently, the estimated cost of chipping increased from €15 odt^{-1} for the CTL roundwood to €17 odt^{-1} in the wood fuel assortments. The overall cost of harvesting and forwarding of roundwood was estimated at €30.50 m^{-3}. As the INT method

Table 5: *Productivity and cost of the machine system using the harvesting methods. Standard deviation in parenthesis.*

Treatment	CTL	INT	WT
Machine Productivities			
Harvester			
Harvester time (PMH ha^{-1})	9.2 (1.2)	9.5 (1.2)	8.1 (0.1)
Harvester cost (€ PMH^{-1})	143.1	143.1	143.1
Harvesting cost (€ ha^{-1})	1321	1355	1159
Harvesting cost of roundwood (€ m^{-3})	21.0	-	-
Forwarder			
Forwarder time (PMH ha^{-1})	5.7 (0.4)	8.9 (0.5)	9.3 (0.8)
Forwarder cost (€ PMH^{-1})	105.7	105.7	105.7
Forwarding cost (€ ha^{-1})	602	944	987
Forwarding cost of roundwood (€ m^{-3})	9.6	-	-
Chipper			
Chipping productivity (odt PMH^{-1})	23.3	19.8	20.1
Chipper cost (€ PMH^{-1})	345.5	345.5	345.5
Chipping cost (€ odt^{-1})	14.8	17.4	17.2
Machine system cost			
Cost of roundwood at roadside (€ m^{-3})	30.5	30.5	-
Cost of wood fuel at roadside (€ GJ^{-1})	6.2	4.6	4.1

resulted in the production of both roundwood and wood fuel at the same time, it was not possible to identify the time associated with each assortment separately. To overcome this, the roundwood cost of €30.50 m^{-3} (as estimated for the CTL method) was assigned to the small sawlog produced using the INT method, and the remaining cost was spread over the remaining biomass. The machine system cost for wood fuel was estimated as follows: €6.20 GJ^{-1} using the CTL method, €4.60 GJ^{-1} using the INT method, and €4.1 GJ^{-1} using the WT method.

Influence of moisture content on quantification of biomass by volume, weight, and energy

Moisture content is highly variable in wood fuel, and is strongly influenced by length of storage time and time of year (Hakkila 2004). Results were analysed to investigate the influence of moisture on energy value of the wood fuel assortments. Small sawlog was excluded from the CTL and INT methods.

Figure 5 shows the estimated volume of the wood per hectare and also the estimated range of the total weight per hectare according to moisture content. As volume is largely unaffected by moisture content, the volumes per hectare remain constant over a range of moisture contents. The total weight of the CTL wood fuel changes from 53 t ha^{-1} at 60%, to 30 t ha^{-1} at 30%. Likewise, the range of the total weight of the INT wood fuel is estimated at 101 t ha^{-1} at 60% to 58 t ha^{-1} at 30%, and the WT wood fuel is estimated at 114 t ha^{-1} at 60%, and 65 t ha^{-1} at 30%.

Figure 6 illustrates the estimated energy content in Mega Watt hours (MWh) per hectare at a range of moisture contents and again the total weight of the wood fuel per hectare. The energy content per hectare using the CTL method was estimated to range between 87 MWh at 60% MC, to 102 MWh at 30% MC. The INT and WT methods have a much higher energy content, as more biomass was mobilised using these methods. The energy content ha^{-1} using the INT method was estimated to range from 166 MWh at 60% MC, to 195 MWH at 30% MC, and using the WT method the

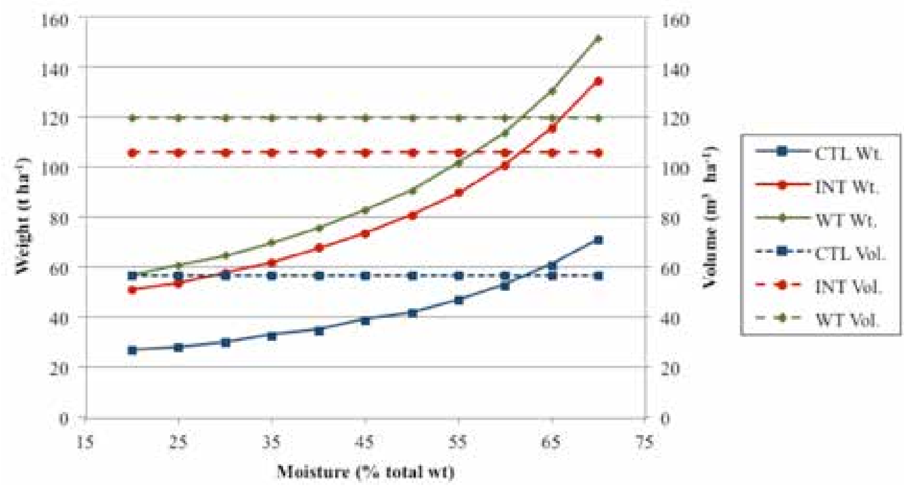

Figure 5: *Comparison between methods of the influence of moisture content on variation between mobilised wood fuel volume (m^3 ha^{-1}) and weight (t ha^{-1}).*

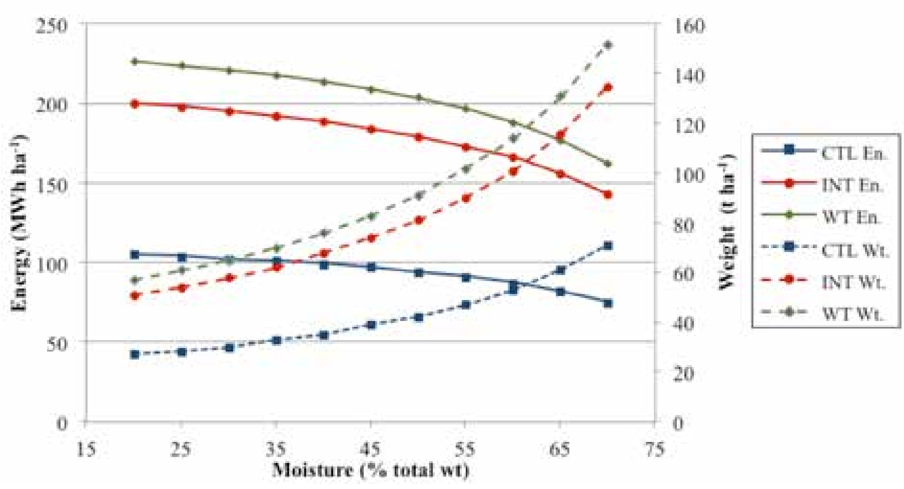

Figure 6: *Comparison between methods of the influence of moisture content on variation between mobilised wood fuel energy content (MWh ha^{-1}) and weight (t ha^{-1}).*

energy content per hectare was estimated to range between 188 MWh at 60% MC, to 221 MWh at 30% MC.

Discussion

The additional biomass mobilised using the INT and WT methods arises largely from the inclusion of branches and tree tops at the time of felling, and not from harvesting additional trees. The harvester cost per hectare was slightly lower for WT harvesting than the INT or CTL methods. CTL and INT harvester costs were the same, and importantly, the same volume of small sawlog was realized from each of these methods. The forwarding costs ha^{-1} were higher for extracting wood fuel, as a direct result of more biomass being brought to the roadside. The chipping cost was similar for all products. The data showed the cost to be slightly less when chipping roundwood, but this information is based on a single plot per treatment so these results should be interpreted cautiously.

The costs estimated are similar to previous research carried out in Ireland Kent et al. (2011) ran a series of wood energy supply chain studies in Ireland and found that WT harvesting was the most cost effective, ranging from €2.22 GJ^{-1} to €4.36 GJ^{-1}. The WT system trialled by Kent et al. in 2007 and 2008 was a terrain chipping system, which was purpose specific to produce wood fuel. In this study, it was found that WT harvesting costs with a harvester, forwarder and a road side chipper were €4.1 GJ^{-1}, which is at the upper end of the Kent et al. results, but the system also had the flexibility of producing roundwood when required. The same authors also reported costs using the CTL method of €5.65-8.64 GJ^{-1}, and costs using the INT method of €5.05-7.52 GJ^{-1}. In this study, costs using the INT method were lower, at €4.60 GJ^{-1}.

The natural drying of wood fuel was poor during the trial period. Further investigation needs to be carried out to determine if the material can be dried more effectively in the forest before forwarding. It is in the interest of wood fuel suppliers to reduce the moisture content of wood fuel to maximise the energy content and reduce transportation costs of the material. It can be seen from the data that as moisture content declines, the weight decreases and the energy content increases. Quantification by weight is the simplest and often the preferred method for trade purposes, but conflict may arise if the forest owner is unable to obtain a premium for selling seasoned wood with a low moisture content. Wood destined for chipping needs to be monitored during storage so that it is at acceptable moisture content before chipping. It is therefore important that all parties in the management of the supply chain are incentivised to reduce for moisture content to optimise the energy potential of this resource.

The impacts of making branch and tree top material unavailable as a brash mat were not evaluated in this study, but it is important to note that soil damage is a possibility, especially on sites with low carrying capacity, particularly if the operation is carried out during wet weather. INT or WT harvesting should therefore only be prescribed for sites where the risks of soil damage are considered low. One of the benefits of using the INT or WT methods, with a machine system that is capable of performing a CTL harvesting, is that the machines can use a brash mat on sites where it is needed, or on parts of a site where numerous machine passes are required. It should also be noted that the indicative figures taken from EN ISO 17225-1: 2014 for the nitrogen content of wood fuel with significant amounts of needles is five times higher than that of the wood fuel from roundwood. This may have implications for forest nutrient cycles. Investigation of these impacts was outside the scope of the study, but they should be evaluated in an Irish context, given that the demand for wood fuel is likely to increase in the future. A practical mitigation approach to limit nutrient loss may be to leave the biomass within the forest during the seasoning period, so that the needles fall off in the stand, and then forward the material to the roadside, as outlined by Kent et al. (2011). This may, or may not, facilitate biomass drying and so should be investigated. It should also be noted that wood fuels with needles or leaves included are not suitable for combustion as they can lead to boiler corrosion.

The ash content of the INT and WT wood fuel chip were higher than the CTL chip. There was also more fine material in the chips derived from biomass containing branch material, and the size of the chips fell into a lower quality classification. The woodchip produced in this trial was accepted for co-firing at a peat and biomass electricity generation plant. The chip made from the CTL roundwood could be used in smaller commercial boilers and these users may be willing to pay a higher price for wood fuel. It should be noted that the marketability of the lower quality chip may be limited to a few large scale industrial users in the country that have large boilers and robust infeed systems that can handle large wood particles containing higher moisture and ash contents. Conversely, there may be more market opportunities at a local level for higher quality material, thus also reducing haulage costs. However the ability to produce this higher quality chip is a function of the raw material, seasoning conditions, and chipping technology, but a large proportion of the biomass is not usable. Another aspect of biomass supply is the efficiency of the boilers for which the wood is destined, an important aspect in the context of carbon accounting. This may be an important consideration in the choice of supply chain, as the combustion technology to either generate electrical power at a large scale, or heat at a smaller scale, may have different efficiencies.

The INT and WT methods described in this paper are still not commonly used in Ireland. The results of the study revealed that these methods show promise, perhaps allowing more wood than previously estimated to be supplied from the emerging private sector resource. This new source of wood may help bridge the gap between supply and demand of biomass in Ireland and may also encourage more private sector owners to thin their stands, especially given that these operations may be economically viable.

Conclusions

Whole tree (WT) and integrated (INT) harvesting methods of thinning a Sitka spruce can mobilise a larger amount of biomass from the forest compared to cut to length (CTL) harvesting, while still delivering the same silvicultural stand benefits.

The machine system costs are lower for the WT and INT methods than for the CTL method.

The costs presented in this paper applied only to the operational costs and did not take into account business and management costs or other returns to the landowners. In addition, the biomass fuel may require extended drying periods at the roadside, so payment may be delayed, thus adding more cost.

Cost-benefit financial analysis, using market prices for the products, should be undertaken to determine the optimal method of harvesting wood to maximise the return from thinning.

The conversion from volume to weight to energy is affected by moisture content changes over time. The price paid for wood fuel should reflect the positive impact of seasoning, so the moisture content of the wood should be considered at the time of sale.

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References

Ackerman, P., Belbo, H., Eliasson, L., De Jong, A., Lazdins, A. and Lyons, J. 2014. The COST model for calculation of forest operations costs. *International Journal of Forest Engineering* 25: 75–81.

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

CRDG: COFORD Roundwood Demand Group. 2011. All Ireland Roundwood Demand Forecast 2011–2020. COFORD, Dublin.

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

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

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

EN 15103. 2009. *Solid biofuels - Determination of bulk density*.

EN 15149-1. 2010. *Solid biofuels - Determination of particle size distribution*. Oscillating screen method using sieve apertures of 1 mm and above.

Forest Service. 2013. *National Forest Inventory – Republic of Ireland. Results Covering the National Forest Inventory, 2009 to 2012*. Johnstown Castle, Co. Wexford.

Hakkila, P. 2004. *Developing Technology for Large Scale Production of Forest Chips*. Wood Energy Technology Programme 1999–2003. TEKES, Helsinki.

IFA. 2015. *IFA Quarterly Fuel Prices Survey*. Available at http://www.ifarm.ie/input-costs/fuel-costs/ [Accessed August 2015].

Karjalainen, T., Zimmer, B., Berg, S., Welling, J., Schwaiger, H., Finer, L. and Cortijo, P. (Eds.) 2001. *Energy, Carbon and Other Material Flows in the Life Cycle Assessment of Forestry and Forest Products: Achievements of Working Group 1 of COST Action E9*. Discussion paper 10. European Forest Institute, Joensuu, Finland.

Kent, T., Coates, E. and Kofman, P. 2011. *Harvesting Wood for Energy*. An investigation into cost effective wood fuel supply chains from Irish forestry. COFORD, Dublin.

Lan, Z. 2001. *A cost model for forest machine operation in wood cutting and extraction*. Activities at the University of Helsinki Partner number 42001-03-22. Helsinki.

Lyons, J. 2015. *Harvester and Forwarder Cost Models*. [Computer software].

Magagnotti, N. and Spinelli, R. 2012. *Good Practice Guidelines for Biomass Production Studies*. COST Action FP-0902. CNR IVALSA, Italy.

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

Miyata, E.S. 1980. *Determining Fixed and Operating Costs of Logging Equipment*. North Central Forest Experiment Station, Forest Service, US Dept. of Agriculture.

Murphy, G., Lyons, J., O'Shea, M., Mullooly, G. Keane, E. and Devlin, G. 2010. Management tools for optimal allocation of wood fibre to conventional log and bio-energy markets in Ireland: a case study. *European Journal of Forest Research* 129: 1057–1067.

NSAI. 2014. EN ISO 17225-1: 2014. *Solid biofuels – Fuel Specifications and Classes*. Part 1: General requirements.

Phillips, H. 2011. *All Ireland Roundwood Production Forecast 2011–2028*. COFORD, Department of Agriculture Fisheries and Food, Dublin.

Prada, M., Martínez-Alonso, C., Sanchez-García, S.and Canga, E. 2015. Analysis of three forest chippers: productivity, costs and GHG emissions in Northern Spain. *Journal of Cleaner Production* 101: 238–244.

Weise, G., Nick, L. and Forbrig, A. 2009. *Test Report Harvester John Deere 1070 D with Harvester Head 745* (corresponds to Timberjack 1070 D). KWF, Groß-Umstadt.

Exploring market opportunities for Short Rotation Forestry in the current Irish wood processing and solid biofuel sectors

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Abstract
Short Rotation Forestry (SRF) is expected to increase in Ireland in response to the increasing demand for fibre products and fuel for renewable energy targets. A survey was carried out of 30 companies in the energy, fibre and sawmills sectors to assess their perceptions on the suitability of SRF species as a raw material. Also data was gathered on current company production, scale, material requirements, species used, price paid and source of supply. The objective was to identify market opportunities, if any, for growers of SRF.

The raw material intake for interviewed companies ranged from 400 to 650,000 tonnes per annum and the price they paid at the mill gate for softwood roundwood varied from €34 to €108 per tonne, with price aligned with piece size but not quality. Most of the interviewees (76%) were not familiar with SRF, however 30% of companies were favourable towards using SRF material for wood fuel and for pallet manufacture. A further 34% were negative about the suitability of SRF as a raw material, with the other 36% expressing no opinion. Information gaps were identified in wood and fuel properties, drying rate and particularly the scale of supply that would become available. Views were mixed regarding forecasted gap between roundwood supply and demand, with sawmills reporting a shortage of sawlog. Instead, the wood energy sector indicated plentiful supply but insufficient market development, which may indicate renewable energy policy targets, will be missed without support measures.

Keywords: *Fast-growing plantations, market survey, wood fibre, wood energy.*

Introduction
Demand for wood products is expected to increase internationally. Forecasts show that demand for wood based products such as fibre boards, wood fuel and paper, supplied from fast growing plantations, will increase even faster than other wood products (Elias and Boucher 2014). The silvicultural practice of producing woody biomass from sustainable fast-growing plantations on agricultural land or suitable forest land on a reduced rotation length is known as Short Rotation Forestry (Christersson and Verma 2006). SRF management (e.g. tree density, fertilization, harvesting cycles, etc.) is less intensive than conventional agricultural crops or Short Rotation Coppice (SRC) but more intensive than conventional forestry, which means that SRF occupies a niche between the highly productive systems and conventional forestry (O'Reilly et

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al. 2014). SRF rotation length is usually between 8-20 years, longer than the two to five year cycle of SRC (Crops for Energy Ltd. 2015). SRF has advantages as single stemmed trees can be planted in areas unsuitable for SRC and all operations are performed using conventional forestry equipment whereas SRC requires specialised machinery (Biomass Energy Centre 2016).

A wide range of products are manufactured worldwide from SRF, although these fast growing plantations are mainly used to produce cellulose, energy and fibre boards (Elias and Boucher 2014). In recent years wood production from SRF has increased due to increasing environmental constraints on harvesting native forest (Sánchez Acosta, et al. 2008). Globally, eucalyptus (*Eucalyptus* spp.) are the most common species used for fast growing plantations and have the potential to help to meet world demand for wood (Laclau et al. 2013). Eucalyptus plantations, grown in a short rotation (10-16 year rotation), have been mainly used by the cellulose industry in the past decades in the Iberian Peninsula (Ruiz and López 2010). Other uses for eucalyptus, such as furniture, flooring, veneers and fibre boards, increased from local use to international markets since 2000 (Sepliarsky 2007). Poplar plantations in Italy, also grown in a short rotation (10-18 year rotation), have been traditionally used for plywood, pallets, crates and paper pulp (Coaloa and Nervo 2011).

The current area of SRF in Ireland is very limited. Keary (2003) estimated that there were 80 ha of hybrid poplar plantations in Ireland and it is unlikely that this area increased as poplar was not an approved species under the Afforestation Grant Scheme until 2014. Coillte have established plantations of Eucalyptus species since 2008 on reforestation sites, particularly in the south and east, expanding on field trials laid down in 1993/94 (Thompson, et al. 2012). An unpublished survey of the Coillte inventory carried out in November 2014 by WIT indicated that there were 333 ha of eucalyptus on 53 sites, established over the previous six years.

The main wood industry sectors in Ireland are the panel boards mills and sawmills, with the wood energy sector emerging recently (IFFPA 2015). The panel board mills used a total of 1.38 million cubic metres of wood fibre (pulpwood, woodchips, sawdust and used wood) in 2014 and this is forecast to increase to 1.6 Mm^3 by 2020 (COFORD 2015). In 2014, a total of 1.95 Mm^3 of roundwood was used by the sawmills, including large sawlog or sawlog, mainly used for construction sawn timber and small sawlog, used for pallets, fencing, packaging and small dimension construction timber. All Irish roundwood was used indigenously and due to a shortfall, additional logs were imported from Scotland (IFFPA 2015). Also demand for wood biomass for energy is forecast to increase from 0.99 Mm^3 in 2014 to more than 1.87 Mm^3 in 2020 (COFORD 2015). This is to help to meet Ireland's renewable energy targets which are set to increase to 16% of total energy supply by 2020 (European Directive 2009). The percentage of renewable energy contributing to the Irish Gross Final Energy Consumption in

2013 was 7.8%, almost half of the 2020 target (Howley, et al. 2014). Across all forest industry sectors, COFORD (2015) predicted a gap of 0.9 Mm^3 between supply and demand by 2020.

Irish forest policy is promoting SRF afforestation through targeted support measures to contribute to meet this forecasted supply-demand gap for fibre, energy and other wood products (COFORD 2015). A new grant premium category for Forestry for Fibre was included in the Irish Forestry Programme 2014-2020 (DAFM 2014). The planting target for fibre and energy within the programme is 3,300 ha by 2020. The species selected under this scheme are specific eucalyptus species (*E. glaucescens* Maid. and Blakeley, *E. gunnii* Hook. f., *E. nitens* Dean and Maid., *E. rodwayi* A.T. Baker and H.G. Sm. and *E. subcrenulata* Maid. and Blakeley), Italian alder (*Alnus cordata* (Loisel) Desf.), hybrid aspen (*Populus tremula* × *tremuloides*) and a list of specific clones of hybrid poplar (× *Populus* spp.) (ibid.). All the proposed species covered by the Forestry for Fibre grants are broadleaved species, capable of high productivity over a short rotation.

A market survey is "a research method for defining the market parameters of a business" (Entrepreneur 2016) and is used to investigate market development and marketing opportunities (Bryman and Bell 2003). The nature of market surveys is often qualitative and associated with emergent research design. Particularly when there is very little theory, structure or framework in the research area, an inductive qualitative approach is chosen (Burnard et al. 2008). Emergent research design uses the data collected to develop the structure of analysis. This means that the sample selection and size cannot be decided at the beginning as this will depend on the course of the research (Denscombe 2003).

Interviews are frequently used in qualitative research to secure a maximum number of responses, collect high quality information and to contextualise the responses and the relations between them. Interview studies usually involve thematic content analysis. This type of analysis is generally known as grounded theory (Denscombe 2003) and is based on identification of the main emergent themes from the qualitative data collected, by following these steps:

- a broad coding of the data into different categories or themes;
- identification of the main themes and relations, so categories are grouped or merged;
- these themes and groupings are then tested by further collected data;
- finally, more and less popular responses on various themes are identified and direct quotes from a wide range of participants are chosen to illustrate those themes (Burnard et al. 2008, Anderson 2010).

Market surveys have been carried out in the forestry sector to identify market development (Perkins et al. 2005, Mendell et al. 2007) and marketing of alternative and not well-known timber species (Venn and Whittaker 2003, Nicholas and Garner 2007). Some studies have used NVivo (QSR International Pty Ltd., Australia), specialised software developed for qualitative data analysis and used in academia, government, business and social science research. In forestry, this tool has been used to analyse opinions of stakeholders and forest owners on emergent forest markets in recent years; for example in the forest biomass energy market (Silver et al. 2015) and the forest carbon market (Thompson and Hansen 2012).

Current Irish forest policy measures promote SRF as a means to bridge the predicted gap in wood biomass supply and demand. The success of this policy will depend in part on the readiness of the wood industry in Ireland to use SRF as a source of raw material. The objective of this study was to explore the Irish industry's perceptions and knowledge of SRF and identify if there are real market opportunities in Ireland for raw material that SRF growers could supply in the future.

The study, carried out in the form of a survey, aimed to investigate species suitability for particular market segments, price, material specifications (e.g. dimensions, certification, moisture content), market scale and infrastructure. This type of information is useful in order to study the economic sustainability of this land use, which is a key principle of sustainable forest management, as well as aid in determining return on investment to growers of SRF relative to other land uses.

Materials and methods

A survey was carried out on market opportunities for SRF of the Irish wood processing and solid biofuel sector between October and December 2015. The methodology used in this survey is summarised in Figure 1.

Approach

Qualitative analysis was used to collect the range of industry views concerning SRF as these perceptions could not be captured with an absolutely quantitative approach. Due to the novelty of SRF in Ireland an inductive qualitative approach was chosen. A thematic content analysis or grounded theory was used to analyse this qualitative data. In addition, some quantitative information was sought from the interviewed people (price, raw material amount and dimensions) and basic descriptive statistics were applied to the data.

Sampling frame: list of potential SRF users

The main sources used to develop the initial list of potential SRF users for energy were the catalogue of Irish wood fuel companies produced by the Irish Bioenergy Association (IrBEA 2013) and the SEAI List of Known Wood Fuel Suppliers (SEAI 2015), supplemented by work done by Mockler and Kent (2014).

Other potential users of SRF were identified by online search and in databases

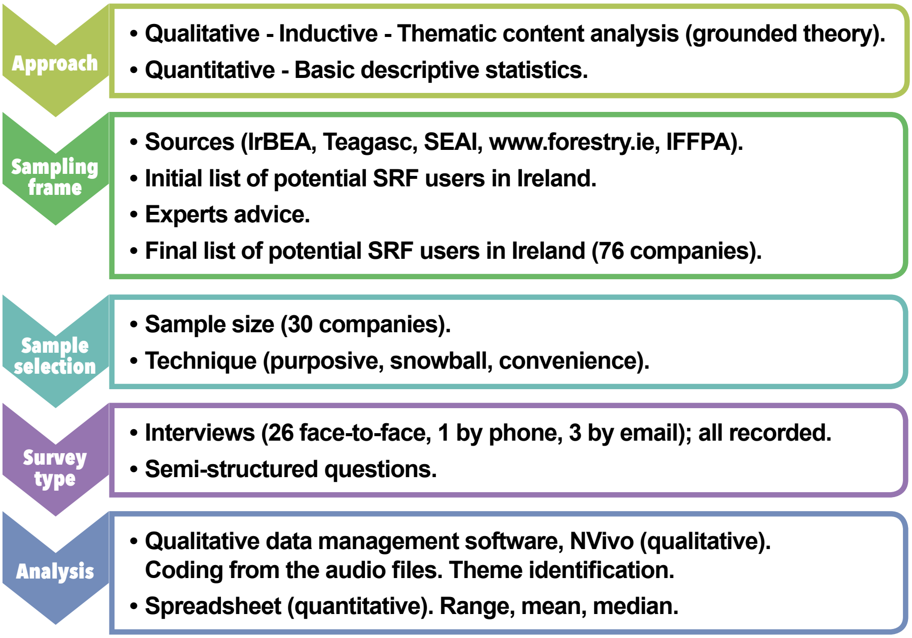

Figure 1: *Outline of the methodology used for the market survey.*

such as the contact list for timber buyers and contractors developed by Teagasc (2014) and the forestry directory (Forestry.ie). The annual overview of the Irish forestry and forest products sector produced by the Forestry and Forest Products Association (IFFPA 2013) was also used to identify companies.

The main survey focused on companies that use raw material from the forest. However, a number of secondary users were also interviewed to get a better insight into woodflow in the Irish market. Furthermore, some of the interviewees were not only users of raw material from the forest but also forest owners or harvesting companies. This broadened the scope of the survey and helped to get a more comprehensive understanding of the market.

After an initial list was finalised, the following experts on the Irish timber and wood fuel markets and fast growing species were contacted for advice on the survey scope and company contact list: Noel Gavigan, Irish Bioenergy Association; Eoin O'Driscoll and Gordon Knaggs, authors of the annual Woodflow in Ireland COFORD report; and Kevin J. Hutchinson, expert on eucalyptus (Thompson et al. 2012). On advice from the experts, the sawmill sector was included in the survey, in order to consider the possibility of using SRF for pallet and fencing material. This idea of looking for higher value products was supported by literature. Other countries first introduced SRF with the target of producing pulpwood for the cellulose and energy sectors and higher value markets developed later once SRF became established.

Experts also helped to identify companies that were no longer in business and to add missing companies to the list.

This final list was revised and updated again throughout the interview process as new companies were nominated by the interviewees (see sample selection). The final list was composed of a total of 76 companies, representative of the Irish energy, fibre and sawmills sectors.

Sample selection: technique and sample size

Purposive sampling, snowball sampling and convenience sampling were the techniques used to select the interview sample. The sample size and selection was decided throughout the interview process due to the emergent research design nature of the survey. Purposive sampling was used because it was planned to interview people from the different sectors among those who showed interest in being interviewed in a first phone call contact. Snowball sampling refers to some of the interviewees providing new contacts interested in participating in the survey. Convenience sampling was required because interviews were scheduled in order to meet several companies in the same region on the same day due to time and cost constraints.

From the total of 76 companies that were identified, 30 were successfully surveyed. More companies were first contacted (53) but some were excluded for different reasons:

- did not answer the phone after several calls in several days;
- were not interested in participating in the survey;
- were too busy and could not commit to an interview.

The 30 surveyed companies were selected to represent all the target sectors and different regions of Ireland (Figure 2). Through the survey process the main potential users of SRF were identified as the firewood, woodchip, panel boards, pallet and fencing sectors. Other potential users of SRF were also explored and interviewed: construction timber, specialised sawmills, bark and woodchip for landscaping, animal bedding, pellet producers and power plants.

The identified and interviewed companies were mapped, so a spatial distribution of the identified and sampled potential users is shown in Figure 2.

Survey type

Companies were surveyed by interview. Questions focused on perceptions and current knowledge on SRF as a potential raw material (e.g. What can you say about SRF? and about the new grants for forestry for fibre? Do you know of any SRF plantations? Would you consider using SRF material?), availability now and into the future of forest resource (e.g. do you think there is balance between supply and demand?), the

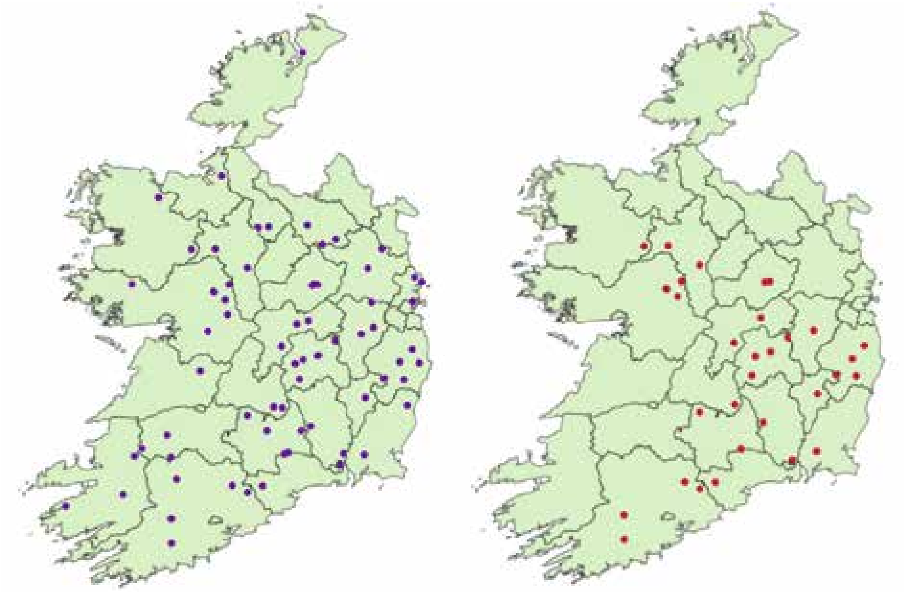

Figure 2: *Left: Potential SRF user companies in Ireland. Right: Companies that were sampled (interviewed).*

raw material used by the company (e.g. where do you source your raw material? How much do you pay for it? What are the maximum and minimum diameters and lengths you can use? Any other requirements?).

The interview was semi structured, in that, a clear list of questions was generated but there was flexibility to allow the interviewee to come up with related ideas and speak more broadly about the topic.

Most of the interviews, a total of 26, were face to face in order to get better quality information. However, three companies preferred to be interviewed by email and one by phone. The face to face interviews and interview by phone were recorded using the free, open source, cross-platform audio recorder software Audacity (found at: audacityteam.org). All the participants were asked for consent of recording before the interview and all accepted it. A unique identifier (company ID) was allocated to each company in order to keep the data anonymous. The average duration of the interviews was 40 minutes, ranging from 16 to 78 minutes.

Analysis

Survey responses were evaluated with NVivo, while a spreadsheet was used to compile the quantitative data. The method used for analysis of the qualitative data was grounded theory. This involved identifying themes and detailed examples of those themes, emerging from the data collected.

Results

The results from the interview analysis were described, including direct quotes from the interviews to illustrate the qualitative analysis and tables to report the quantitative analysis.

Business products

There was a tendency for some companies to be involved in more than one product or even sector. Table 1 shows that nine companies were involved in two products and four in three products. Some products were very seasonal so a complementary product was needed: "The main reason we went into the firewood was because the fencing was very quiet into the winter". Also, companies sought to make the most of the material they bought, for instance sawmills often sold or used their own residues as wood fuel.

Perceptions of Short Rotation Forestry

Most of the participants (76%) were not familiar with SRF defined as single stem plantations, on 8-20 year rotations. Seven of the interviewees thought of short rotation coppice willow instead. "My vision of SRF is willow and for those crops to be successful you need good fertilizer".

Just six out of the 30 interviewees were aware of the Forestry for Fibre afforestation grant scheme. In spite of the majority not being familiar with SRF terminology, 37% had experience using eucalyptus or poplar wood and a further 27% had heard of these species (total 64%). However, these participants confirmed that their current knowledge was limited. Forty percent of the participants were able to say something

Table 1: *Companies interviewed by sector and sub-sector.*

Market sector	Sub-sector	No. of companies interviewed	Company ID
Wood energy	Firewood	10	A, D, E, F,G, H, I, J, K, L,M
Wood energy	Woodchip	8	D, E, F, L, W, X, Y,Z
Wood energy	Power plant	2	S, AA
Wood energy	Pellet	2	B, DD
Fibre	Panel boards	2	BB, CC
Sawmill	Pallet	9	Saw: B, K, R, S, V Pre-cut[a]: M, N, O, P
Sawmill	Fencing	5	Saw: B, C, R, V Pre-cut: I
Sawmill	General	3	S, U, V
Sawmill	Cut to order	2	Q, T
Other fibre users	Horticultural landscape	2	A, Y
Other fibre users	Bark	1	A
Other fibre users	Animal bedding	1	N

[a] Pre-cut: did not purchase roundwood.

about the wood properties of these species: "eucalyptus looks like softwood, it's very pale…burns ok…poplar is too hard to dry"; "eucalyptus cracks…it is very difficult timber to deal with, very difficult to dry…but when you saw is beautiful, great pattern"; "poplar, eucalyptus…I wouldn't say is very strong…"; "poplar doesn't burn very well it gets black and people think firewood isn't dry".

Almost a third (30%) of the participants, all of whom knew or had experienced using SRF wood, would consider using this material. Most of them were from the wood energy sector (86% of that), while two small-medium size sawmills expressed interest in using SRF to produce pallet material. These two sawmills had less advanced technology so they stated that they could adapt easily to different species and volumes. However, all the larger sawmills were not favourable toward SRF. The main reasons appeared to be the large volume required in order to change the manufacturing process and make the production effective:

> We just don't have the volume in this country...if we were setting up the sawmill for hardwoods...it's a completely different plant, it's a completely different market and we don't have the species on the ground, we don't have the hectares planted…we could change the plant and there would not be material to run one day.

Within the wood energy sector, the firewood sub-sector and the power plants were the most positive. The woodchip sub-sector was less enthusiastic. It might be because they consider the purchase price would be too high as SRF species are hardwoods and the current prices for hardwoods are prohibitive for the woodchip suppliers: "…[we take] any softwood, preferably hardwoods, but you can't buy hardwoods, it is too expensive...you can't compete with the firewood."

The fibre board mills were negative toward using SRF. There was a general perception among all sectors that SRF was just a crop for fuel: "These are crops for biomass production; they will not be suitable for sawn products."

A set of concerns towards SRF were revealed in the interviews, around the perceived risk due to past experiences of unsuccessful new crops: "…be careful because miscanthus [*Miscanthus x giganteus*] was fantastic 10 years ago, now nobody wants it."

Another concern of using alternative species was that customers complain about species different to Sitka spruce: "If I took in Douglas, it's a better timber but the customer would complain, they just don't know it's a better timber, they just see a piece of timber of a different colour and they'll say, oh, an issue, problem."; "…because our customer's requirements...we can't afford to take the chance, we have to keep our quality up and to keep the quality up, we need spruce."

Seven of the interviewees expressed the view that it would be better to plant more Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in traditional rotations instead of SRF.

Although they admitted species diversification was needed, their point of view was that Sitka spruce was the best species to grow in Ireland:

> Rather than growing short rotation crops for fibre or biomass, this land could be used for growing Sitka spruce on a 35-year rotation...the benefit is a strong saleable product, which has high demand, that can be put into years of service, as construction products, locking up carbon for potentially hundreds of years, before finally being available for fibre or biomass. We have a massive natural advantage to growing Sitka spruce in Ireland, the problem is, we are not growing enough of it!

There was also a repeated opinion of planting more Sitka spruce and using harvesting residues for energy instead of establishing energy crops as there was a perception of plenty of forest waste material available for energy:

> I don't see the sense in SRF, I think we should be pushing forestry, planting trees and using the branches of the trees, and we are doing two jobs: we are supplying logs to sawmills and we are supplying energy rather than the energy crop just being energy…we grow very good Sitka spruce…

The perceived difficulty to convince land owners and industry to change species was another concern: "The industry that is in the country at the moment is based on Sitka spruce…if somebody is thinking of changing species they should put a lot of consideration into it."

Users who had experience using eucalyptus and poplar were mainly negative about their use due to problems with drying and sawing processes. Regarding eucalyptus, concerns about the bark were also identified:

> Although the quick yield was great and the timber quality was good, we had huge problems with the bark of the tree. This created a lot of problems in our production process as it blocked chutes and conveyors and wrapped itself around pulleys which stopped conveyors.

In spite of this, they agreed SRF had potential once the appropriate management, drying and sawing techniques are clear.

Participants affirmed they would need more information about SRF in order to consider using it and highlighted the importance of clarifying uncertainties about SRF for market development to proceed. Interest was expressed in having more information on:

- financial return and market for SRF -13 interviewees.
- combustion properties such as calorific value, chemical composition and boiler reaction -nine interviewees.
- moisture content and how long it takes to dry -four interviewees.
- wood properties e.g. straightness -four interviewees.
- availability -four interviewees.

Raw material: quantity, suppliers, distance

The range of raw material intake by company was from 400 to 650,000 tonnes per annum with a median of 5,000 tonnes (Table 2).

Interviewed companies purchased raw material from a variety of sources: Coillte, forest management companies, sawmills and private forest owners. Just 20% of companies relied on one source only. Half of interviewed companies purchased material from two sources and 30% purchased from three sources. Coillte (the Irish semi-state forestry company) supplied raw material to 18 of the 30 companies, but only two companies relied solely on Coillte. Four companies purchased from sawmills only, but a further four companies bought from sawmills in addition to Coillte, forest management companies or private forest owners. Forest management companies entirely supplied six companies and partially supplied a further 14 companies. Only one company purchased all raw materials from private forest owners but another nine companies were partly supplied by private forest owners.

However, the amount of raw material sourced directly from private forest owners was very limited. Interviewees reported that they preferred dealing with forestry companies than directly with forest owners:

> …it's hard to deal with farmers and get a good rate and then in

Table 2: *Annual raw material intake and price paid relative to specification.*

	Annual raw material intake (tonnes[a])			**Price paid relative to specification** (€ per tonne softwood at mill gate)		
Sub-sector	Min	Max	Median	Min	Max	Mean
Firewood	170	5,500	1,852	34 (55[b])	42 (85[b])	40 (52[b])
Woodchip	600	50,000	9,012	34	42	39
Pallet and fencing	35,000	150,000	114,167	40	65	52
General sawmill	100,000	350,000	216,667	70	96	84
Bark	20,000	20,000	20,000	23	23	23
Cut to order	3,000	5,500	4,250	100	130 [b]	108
Power plant	500,000	500,000	500,000	-	-	-
Panel boards	500,000	650,000	575,000	-	-	-

[a] Assumed conversion between cubic metres and tonnes was 1 m^3 = 1 t.
[b] Hardwood price.

> the long run it nearly costs you more by the time you have the guys in and the licence got, it just takes too long so it's easier for someone else than for ourselves.

Furthermore, if interviewees dealt directly with forest owners, they had to organise the transport. They were also negative about buying from private forest owners due to the small properties, observing that a lot of work was required for a small amount of raw material.

> They [private landowners] are very nervous and demanding… it's more work for me and if I am dealing with the landowner I might have 10 ha, and then that's a lot of work for 10 ha, if I am dealing with a forestry company is the same amount of work for maybe 200 ha.

Most of the interviewees sourced their raw material from anywhere in Ireland. Mainly sawmills imported some of the material because of the short supply in Ireland (Table 3). Some of the woodchip and firewood suppliers tried to only buy locally (50 km maximum) to save transport costs, but they were finding this difficult:

> Normally within an hour of the yard, 40-50 km of where it has to be processed, it should be the maximum, it should be moving biomass, but the way it is happening at the moment, there is very few outlets for the product… the market at the moment for pulp is small, it is big for board mills but take the price…they use a lot of pulp from the South of the country going to the North at the moment, you talking about 150 miles…

Requirements of raw material: dimensions, species and others

The roundwood dimensions required by each sub-sector are summarised by Table 4, where the specifications include the minimum, maximum and median allowed dimensions. The most common assortments in Ireland are: saw log from the lower section of a stem, usually with a small end diameter down to 20 cm; small sawlog, from the stem mid-section, usually 20 cm large end diameter and down to 14 cm; pulp,

Table 3: *Source of raw material by distance and by sector.*

Sector	Anywhere in Ireland	Anywhere in Ireland and import	Locally (<50 km)
Wood energy	10	2	5
Sawmill	5	7	1
Fibre	2	0	0

Table 4: *Roundwood assortment dimension requirements by sub-sector; values include the minimum and maximum allowed, with the median in brackets.*

Sub-sector	Length (m)	Top diameter (cm)	Bottom diameter (cm)	Assortment
Firewood	1.8-6.7 (3.0)	5-25 (8)	20-100 (45.5)	Pulp
Woodchip	3.0-4.9 (3.0)	7-14 (9)	40-100 (62.5)	Residues & Pulp
Panel board	3.0-3.0 (3.0)	7-7 (7)	35-50 (42.5)	Pulp
Pallet	2.4-7.7 (3.1)	13-18 (14)	30-120 (40.0)	Small sawlog
Fencing	1.6-3.8 (3.0)	7-16 (13)	16-40 (23.0)	Pulp & small sawlog
General sawmill	2.5-7.3 (4.9)	14-16 (15)	35-150 (57.5)	Sawlog & small sawlog

from the stem top section, usually with a minimum diameter of 7 cm; and residues are the top, below 7 cm diameter and the branches.

Regarding species, the Irish wood industry is softwood based (58% of the participants use softwood only). The predominant, Sitka spruce, was the industries' preferred species (60 to 100% of the total raw material intake) because of availability, price and wood properties:

> Alternative species are probably not there for us…now we get a bit lodgepole…is very bad timber species, it breaks when you are peeling…the product you are dealing with is still a low value product [round posts for fencing] so, if we are going to hardwood they [customers] wouldn't pay to do it.

Another 27% used mainly softwood but occasionally some hardwood. They also confirmed using mainly Sitka spruce. Other softwoods used were Norway spruce (*Picea abies* (L.) H. Karst.), larch (*Larix* spp.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco) and lodgepole pine (*Pinus contorta* Dougl. ex Loud).

Just 15% of the companies, all from the firewood sector, use mainly hardwood: "The hardwood is much better: it burns twice as long but you pay more".

Hardwood species used were quoted as being: ash (*Fraxinus excelsior* L.), beech (*Fagus sylvatica* L.), oak (*Quercus robur* L. and *Q petraea* (Mattuschka) Lieblein), alder (*Alnus glutinosa* (L.) Gaertn.) and birch (*Betula* spp).

Another set of requirements emphasised were:

- straightness -10 interviewees;
- appearance (e.g. colour, smell) -six interviewees;
- moisture content and the time wood required for seasoning -five interviewees;
- cleanliness from branches -five interviewees;
- sufficient supply volume -four interviewees;
- combustion characteristics (calorific value, chemical composition, dry matter and ash) -three interviewees.

Purchase: price, point of purchase, units

The prices paid by the surveyed companies varied from €20 to €80 m^{-3} roadside (€34 to €96 m^{-3} at mill gate), with prices aligned with roundwood piece size but not quality. Companies reported prices in tonnes and cubic metres interchangeably. The cheapest raw material was bark (€23 m^{-3} "delivered-in", i.e. at mill gate) and the most expensive was timber from old and large-sized hardwoods used in specialist mills that saw to order (€130 m^{-3} delivered). There was no data collected from power plants and panel boards due to confidentiality (Table 2).

Most prices were given as delivered-in (17 out of 23 responses). Some interviewees gave a haulage rate, averaging €15 t^{-1} and ranging from €5 t^{-1} to €30 t^{-1}, with prices aligned with distance (€30 per approximately 250 km). It was also common to buy roadside (six out of 23 responses), but standing sales were unusual (no responses).

Prices were mostly given in weight units (tonnes) by the private sector and in volume (cubic metres) by the state company. Furthermore, 30% of the interviewees did not use the metric system when describing dimensions. It was very common for lengths and diameters to be reported in feet and inches.

Balance of supply and demand: currently and in the future

Interviewees, by market sub-sector, had different perceptions on availability of and demand for raw material. Demand for woodchip and bark for horticulture was reported to be increasing, so more material was requested by this sector. The woodchip for energy sub-sector has the opposite opinion: demand for woodfuel had not developed in recent years, but the raw material supply is readily available and increasing:

> Getting timber is fine, there is no problem with it, getting rid of it is the problem. It is fine for us because we have our customers already,...there is no order, there is no more development going on, the grants are gone which is a killer, ...we are waiting for, there is talks about bringing the tariff from England over to here.

The latter companies pointed out the necessity of grants, such as the Renewable Heat Incentive in the UK, to develop the woodfuel sector and they highlighted the price of oil as the key determinant for this sector's future. Firewood participants viewed the supply-demand as being in balance at the moment. However, some of the sawmills expressed strongly that there was lack of timber in the country at the moment: "…now every sawmill in Ireland is fighting over the raw material. There is more capacity in this country than there are logs…", while others thought there is balance between supply and demand at the moment.

There were different opinions between and within sectors regarding the availability of raw material in the coming years. Some of those surveyed thought there would be enough wood resources: "…there will be, there was a lot planted 20 years ago…It's flying in, it's coming on." Others opined that there would be lack of supply as demand was going to increase: "If the business happens the way it is supposed to happen there will not be enough timber, there isn't enough planted".

Potential market for SRF in Ireland

A basic analysis of the survey results indicated that the thirty companies had a combined annual raw material requirement of 3,126,120 m^3, or 98 % of the Irish total annual demand of 3.2 Mm^3.

Of the surveyed wood energy companies and sawmills that confirmed that SRF material could potentially be used, the sawmills required 52,500 m^3 of small sawlog, 3.1 m in length and 13-120 cm diameter, purchased at mill-gate on average at €52 m^{-3}. The wood energy companies had a total annual requirement of 512,120 m^3. However, this value was dominated by a single large power station and included approximately 50% imported non-woody biomass and an amount of indigenous biomass, such as miscanthus and forest residues, amounting to an estimated 300,000 m^3. The remaining 212,120 m^3 could be characterised as pulp logs, typically 3 m in length, 5-100 cm diameter, with an average mill-gate price of €40 m^{-3}. In all cases except the large power station, these companies sourced material only within Ireland and two companies preferred exclusively local supply.

Discussion

Currently, the cellulose and veneer industries that use SRF wood internationally are absent from the forestry sector in Ireland. However, the current wood industry in Ireland (panel board mills, wood energy sector and perhaps the sawmills), have the potential to use SRF as these same sectors use short rotation species such as poplar and eucalyptus internationally. This survey confirms that SRF is considered an acceptable raw material by the majority of the wood energy sector and some sawmills. The international experience (Sepliarsky 2007) suggests that additional wood industry sectors will include SRF in their raw material mix as it becomes increasingly available.

While the negative views expressed towards SRF by some industry sectors may be partially attributed to an attachment to Sitka spruce, there were valid technical issues raised on the difficulties of sawing, drying and debarking of SRF species. The reason participants were not familiar with SRF might be partly due to a lack of awareness of this terminology (Silver et al. 2015). Within published literature, there are various definitions for SRF (Christersson and Verma 2006, McKay 2011) and such plantations are often treated simply as fast growing species harvested every 8-20 years. Confusingly, SRF is often applied by authors to short rotation coppice systems.

Although potential SRF users prefer local supply to reduce transport cost, most took material from anywhere in Ireland, so the location of SRF plantations should not be limited to areas adjacent to particular end users. On the other hand, the transport cost and value of SRF will determine maximum viable distance to market. The SRF products identified as suitable by this survey are pulp and small sawlog, which are lower in value compared to large sawlog, so shorter haulage distances may be more economic.

These assortments are also smaller in average dimensions, indicating a smaller mean tree volume compared to current/traditional norms. This suggests short rotation length, higher tree stocking rates or a mix of both could be used to affect target tree volume. However, the tendency of wood-using companies to be involved in more than one sector will require SRF growers to ensure production suitability for diverse markets, rather than targeting a single end use. Furthermore, wood property requirements indicated by sawmills, such as straightness and small knot size, would need to be investigated in SRF wood.

A further point of concern for SRF growers was the clear preference potential SRF users expressed for purchasing raw material from Coillte and private forestry companies rather than small forest owners. This suggests that growers should organise themselves and join a producer group co-operative or sell through a forest management company.

There were diverse opinions about availability and demand of wood resources. While the sawmills agree with the forecast of a shortfall of resources (COFORD 2015), the wood energy sector and particularly the woodchip suppliers have the opposite opinion and state that demand would only increase with grant support. Ultimately, this represents industry feedback to policy makers that current energy policy has defined renewable energy targets for wood biomass, but has not put in place the supports to ensure that these targets are met.

As a shortfall of wood in Ireland was the main reason given by sawmills of importing sawlog, *even if* native material was preferred, SRF could be a real option if supply, quality and processing concerns were addressed. As also found in similar studies, availability of SRF and information on properties are prerequisites for market development (Nicholas and Garner 2007).

Regarding quantity of raw material intake, market expansion will depend on the larger potential users (Venn and Whittaker 2003). However this expansion is difficult as it incurs a significant risk (Perkins et al. 2005) and smaller wood energy companies may first establish the market. In that case, development of SRF may depend on grants for the establishment of firewood and woodchip boilers or fixed rate tariffs on energy prices.

This study had several limitations including the relatively small sample due to the qualitative approach and the heterogeneous data responses from market sectors, scale of production, measurement units for payment and species used. Results should be interpreted with caution and more research in this field would be beneficial.

Companies interchangeably used prices in tonnes and cubic metres and these two different measurement units were perceived as being equivalent. This equivalence is only rarely accurate due to variations in basic density and in particular, moisture content. Currently, these companies pay depending on the raw material source: weight for the private forest sector and volume for Coillte. This interchangeable use of volume and weight units, in addition to using non-metric units to describe dimensions, promotes ambiguity and a lack of transparency in trade. Particularly, as raw material is being supplied increasingly from sources other than Coillte, there may be a need in the wood processing industry to articulate more precisely and consistently (as well as transparently) their raw material needs.

The survey captured a point sample of roundwood prices for the surveyed market sectors. These prices are indicative only, as there is no SRF material supply yet and wood prices vary throughout the year. However, these data do provide a reference of how much potential users of SRF are willing to pay, so set a ceiling on the price SRF material should meet to compete in the market. Knowledge of this price paying potential is a necessary input to evaluate the economic sustainability of SRF in Ireland.

Conclusions

Nine of the companies (30%) indicated that SRF material would be a suitable raw material and they had an annual roundwood requirement of 264,620 m^3 each year. The wood energy sector was the most favourably disposed towards SRF and the other sectors agreed the main use of SRF would be for energy production. Two sawmills indicated that SRF could also be suitable for pallet manufacture.

Other companies had reservations against SRF, including preference for conventionally produced Sitka spruce, poor drying characteristics and other doubts about the wood properties of SRF species and the large volume required for the biggest companies in order to make the production effective. The technical capacity of these wood market sectors to use SRF in production should also be investigated.

Seventy percent of the interviewed companies identified a need for SRF research and education. Evidence of the potential production scale of SRF species in Ireland, in addition to information on wood properties and fuel parameters and suitability to different markets, is needed to inform potential users on the suitability of SRF for their market sector. Current research, under the SHORTFOR project, may provide some of the required information but further research, development and dissemination actions will be required.

As evidence of this, only 20% of the companies were aware of the Forestry for Fibre grant premium category described in the Afforestation Grant Scheme, supporting SRF afforestation. However, this study confirms there is a potential market for SRF material grown under the scheme. The mixed views on a wood biomass supply and demand gap represent a challenge to policy makers. In particular, wood energy producers' insistence that there was raw material oversupply and insufficient market development for renewable energy from biomass suggests that policy targets on renewables may not be met without support measures to stimulate the investment in wood energy.

Acknowledgements

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References

Anderson, C. 2010. Presenting and evaluating qualitative Research. *American Journal of Pharmaceutical Education* 74: 141–152.

Biomass Energy Centre. 2016 Short rotation energy crops. Available at http://www.biomassenergycentre.org.uk/portal/page?_pageid=75,17369&_dad=portal&_schema=PORTAL [Accessed March 2016].

Bryman, A. and Bell, E. 2003. *Business Research Methods*. Oxford University Press, USA.

Burnard, P., Gill, P., Stewart, K., Treasure, E. and Chadwick, B. 2008. Analysing and presenting qualitative data. *British Dental Journal* 204: 429–432.

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

Coaloa, D. and Nervo, G. 2011. Poplar wood production in Europe on account of market criticalities and agricultural, forestry and energy policy. In *Proceedings Tercer Congreso Internacional de Salicáceas en Argentina*, Neuquén, Argentina.

COFORD. 2015. *Mobilising Ireland's Forest Resource*. Wood Mobilisation Group, COFORD. Dublin.

Crops for Energy Ltd. 2015. *Crops for Energy*. Available at http://www.crops4energy.co.uk/ [Accessed October, 2014].

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

Denscombe, M. 2003. *The Good Research Guide: for Small Scale Social Projects*. Open University Press, p. 310.

Elias, P. and Boucher, D. 2014. *Planting for the Future. How Demand for Wood Products Could Be Friendly to Tropical Forests*. Union of Concerned Scientists, Cambridge, MA, USA.

Entrepreneur. 2016 Small Business Encyclopedia. Available at https://www.entrepreneur.com/encyclopedia/market-surveys [Accessed March 2016].

European Directive 2009/28/EC. Council Directive 2009/28/EC of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. OJ L 140/16. Available at http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0028&from=en [Accessed November 2016].

Forestry.ie. *Forestry Directory and Portal*. Available at http://www.forestry.ie/directory [Accessed September, 2015].

Howley, M., Holland, M. and Dineen, D. 2014. *Energy in Ireland*. *Key Statistics 2014*. Sustainable Energy Authority of Ireland.

IFFPA. 2013. *An Overview of the Irish Forestry and Forest Products Sector 2013*. Irish Forestry and Forest Products Association. Dublin, Ireland.

IFFPA. 2015. *An Overview of the Irish Forestry and Forest Products Sector 2015*. Irish Forestry and Forest Products Association. Dublin, Ireland.

Irbea. 2013 *Catalogue of Irish Wood Fuel Companies*. Available at http://www.irbea.ie/index.php/bmtc/147-2013-catalogue-of-wood-fuel-suppliers [Accessed February 2016].

Keary, K. 2003. Country report for Ireland. *First international Conference on the Future of Poplar Culture*. 13-15th September 2003, FAO Headquarters, Roma, Italy.

Laclau, J.P., de Moraes Gonçalves, J.L. and Stape, J.L. 2013. Perspectives for the management of eucalypt plantations under biotic and abiotic stresses. *Forest Ecology and Management* 301: 1–5.

McKay, H. 2011. Short rotation forestry: review of growth and environmental impacts. *Forest Research Monograph* 2: 1–211.

Mendell, B., Morales, V., Bennadji, Z., Moreno, A. and Siry, J. 2007. Financing Uruguay's forestry sector: Survey and case study. *Journal of Forestry* 105: 125–130.

Mockler, N. and Kent, T. 2014. Participation in a wood-fuel quality assurance scheme in Ireland. *Irish Forestry* 71: 63–75.

Nicholas, I. and Garner, S. 2007. A survey of alternative species markets. *New Zealand Journal of Forestry* 52: 10.

The reference should read:

O'Reilly, C., Tobin, B. and Farrelly, N. 2014. Can short rotation forestry play a role in renewable energy demands? *Forestry and Energy Review* 4: 32-34. Available at https://www.teagasc.ie/media/website/crops/forestry/research/Teagasc-shortfor-article-july-14.pdf [Retrieved January 2016].

Perkins, B., Smith, B. and Jackson, G. 2005. *Evaluating Markets for Small Diameter Timber: a Case Analysis in Northern Mississippi*. Center for Forest Products

Marketing and Management. Department of Wood Science and Forest Products. Virginia Polytechnic Institute and State University.

Phillips, H. 2011. *All-Ireland Roundwood Production Forecast 2011–2028*. COFORD, Dublin.

Ruiz, F. and López, G. 2010. History of Eucalyptus, present situation and utilization. In *Proceedings Eucalyptus Species Management, History, Status and Trends in Ethiopia*., Proceedings from the Congress held in Addis Ababa, Ethiopia, 15–17th September 2010.

Sánchez Acosta, M., Mastrandrea, C. and Lima, J.T. 2008. Wood technologies and uses of Eucalyptus wood from fast grown plantations for solid products. In *Proceedings 51st International Convention of Society of Wood Science and Technology*, Concepción, Chile, 10–12th November 2008.

SEAI. 2015. *SEAI -Wood Pellet Fuel Information*. Available at http://www.seai.ie/Grants/GreenerHomes/Wood_Pellet_Fuel_Information/ [Accessed February 2016].

Sepliarsky, F. 2007. Desarrollo de nuevos mercados de madera sólida para Eucalyptus globulus. *Boletín del CIDEU* 3: 109–117.

Silver, E.J., Leahy, J.E., Noblet, C.L. and Weiskittel, A.R. 2015. Maine woodland owner perceptions of long rotation woody biomass harvesting and bioenergy. *Biomass and Bioenergy* 76: 69–78.

Teagasc. 2014. *Contact List for Timber Buyers and Contractors*. Available at http://www.ifa.ie/wp-content/uploads/2013/10/Timber-Buyers-Contractors.pdf [Retrieved September, 2015].

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

Thompson, D.W. and Hansen, E.N. 2012. Institutional pressures and an evolving forest carbon market. *Business Strategy and the Environment* 21: 351–369.

Venn, T.J. and Whittaker, K. 2003. Potential specialty timber markets for hardwoods of western Queensland, Australia. *Small-scale Forest Economics, Management and Policy* 2: 377–395.

A rapid assessment using remote sensing of windblow damage in Irish forests following Storm Darwin

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Abstract
A National Windblow Task Force was set up following the catastrophic windstorm in February 2014. Part of the Task Force's work was to conduct a rapid assessment of wind damage to Irish forests across the Estate (both public and private). The RapidEye satellite constellation was chosen for the acquisition of post-storm image data as it was the most cost effective and flexible data source to map the spatial extent of the wind damage in Irish forests (both public and private). The satellite image data were analysed using a supervised classification. Vegetation indices and textural features were used to assist in the classification. The digital wind damage map generated by the consortium, demonstrated the effective use of remote-sensing for the collection of windstorm forest damage data in Ireland. Within 8 weeks of data delivery, the consortium concluded that at that time, over 8,000 ha of forests were damaged by the storm, approximately 6,000 ha of state forests managed by Coillte Teoranta and a further 2,000 ha forest held in private ownership.

Keywords: *Wind damage, optical remote sensing, vegetation indices*.

Introduction

Background

Windblow refers to the uprooting or breakage of trees by wind. Windblow results when the wind-induced drag force on the tree crown, multiplied over the lever-arm of the stem, results in a turning moment that exceeds the bending resistance of the stem, or the root anchorage (Mitchell 2013). In terms of volume loss, wind is the most important disturbance agent in European forest ecosystems (Gardiner et al. 2010). However, in Ireland, volume loss to wind damage is of more significance. Given the country's geographical position, it is subjected to more intense cyclones, extreme gales and precipitation when compared to other European countries. Historical climatic records for the period 1947-1974 (Gallagher 1974) indicate that our climatic conditions will result in extensive recurrent windblow or endemic windblow - with severe wind storms occurring at 10-15 year intervals, and sometimes more frequently resulting in catastrophic wind damage. Ní Dhubháin (1998) reported that an estimated

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85,000 m^3 of timber are blown over annually in this country based on data collected for State and Coillte Teoranta (Coillte) forest between 1980 and 1997. However, more recent Coillte records show annual average invoicing levels for windthrow material of 241,000 m^3 over the 24 years between 1992 and 2015 (Anon 2016). Considering the national private estate amounts to approximately 47% of the forest area of Ireland (DAFM 2013) and the large area of grant-aided private planting which took place in the 1990's is now reaching maturity, the total national annual volume lost to wind damage is likely to be significantly higher.

Sustained winds (>10 minutes), as opposed to gusts, above storm force 10 are relatively rare in Ireland. Violent storm force 11 sustained winds, have only been recorded on four occasions since 1940 at Met Éireann's Valentia Observatory (McGrath 2015). The last occurrence of storm force 11 was in February 2014 and was associated with Storm Darwin.

Storm Darwin

Between the 5th of December 2013 and the 12th of February 2014, storm force winds occurred on 12 separate days. This series of storms led to a large increase in rainfall throughout the country on soils which were already heavily saturated. The most severe event, named Storm Darwin, occurred on the 12th of February 2014 and was associated with an active depression off the south coast that tracked steadily north eastwards over the country. Figure 1 shows an image captured by NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) of Storm Darwin above Ireland. Cork Airport and Valentia Observatory reported their highest mean wind speeds in 17 years, while Shannon Airport recorded the month's highest gust of 159 km/h, its highest gust for February since records began in 1946.

From the perspective of sustainable forest management, storm damage can have an immediate catastrophic effect: uprooting and snapping trees at mid-height, blocking roads, bringing down electric power lines and creating serious safety hazards. In the medium term, tree clearance needs to take place before the downed timber begins to degrade; also administrative and legal requirements in regard to felling must be considered; harvesting equipment deployed, road access provided and marketing of the timber quickly progressed. As 47% of Ireland's forest area is now spread across many thousands of sometimes inexperienced private owners, a coordinated response was needed after Storm Darwin to support post-storm forest management, felling licence control and post-hazard relief activities.

In the immediate aftermath of storm Darwin, Mr. Tom Hayes T.D., Minister for State for Forestry at the Dept. of Agriculture, established a Task Force to respond to the catastrophic effects the storm had on Irish forests. A requirement to map and estimate the area and volume of wind damage in both public and private forests was

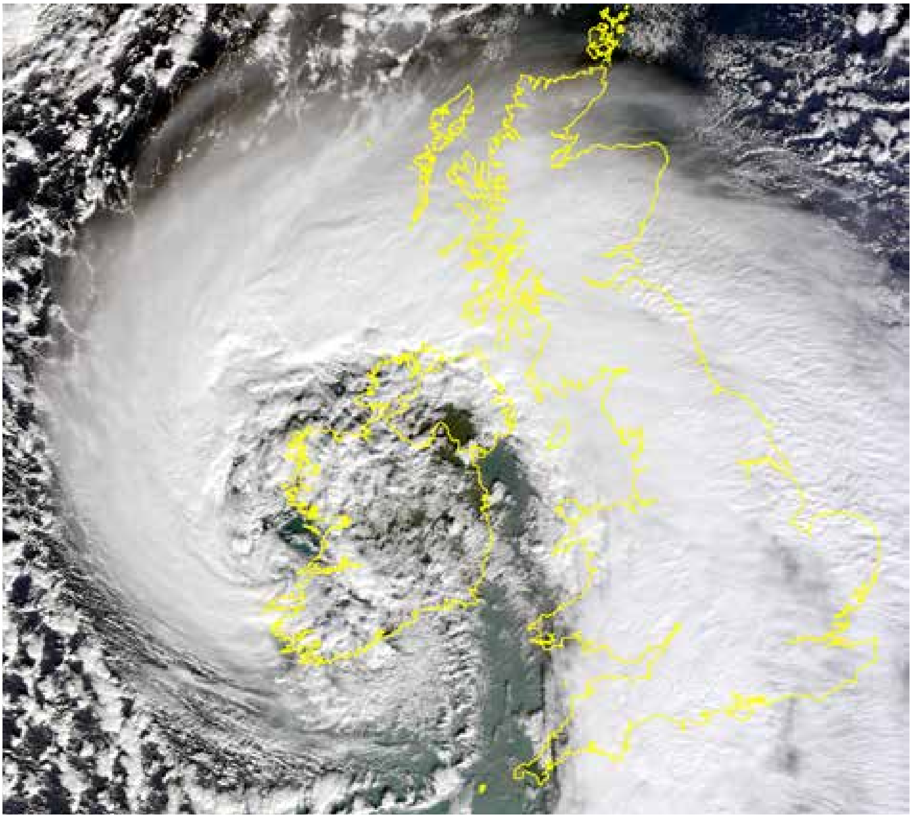

Figure 1: *NASA Earth Observatory image by Jesse Allen, using data from the Land-Atmosphere near real-time capability for EOS (LANCE). Image acquired 12th February 2014. Availabe at http://earthobservatory.nasa.gov/NaturalHazards/view.php?id=83127.*

identified by the Task Force members. A range of data sources and methodologies were reviewed by the Task Force that included field inventory and mapping; aerial photography; airborne laser scanning data and optical satellite imagery. Although the strength of the storm was fully apparent, it was still unknown which areas had been hardest hit. It was therefore essential to utilise data that provided a synoptic view of

Table 1: *Invoiced volumes (000s m^3) from Coillte windblow sales proposals (1992-2015).*

Year	Invoice sales	Year	Invoice sales	Year	Invoice sales
1992	246	2000	921	2008	67
1993	198	2001	387	2009	54
1994	237	2002	234	2010	77
1995	184	2003	113	2011	43
1996	92	2004	66	2012	53
1997	57	2005	54	2013	42
1998	356	2006	52	2014	379
1999	894	2007	56	2015	920

the forests, that could be acquired quickly and cost-effectively and used as the basis for a rapid, reliable, objective and semi-automated approach to damage detection.

In Coillte, as can be seen from Table 1, the sale of windblown timber has been characterised by a managed release following each storm event with a view to protecting the market for public and private timber by reducing the risk of over-supply adversely affecting price. Only when the full scale of the damage is known can this type of strategic action take place. In addition to strategic actions related to the supply of windblown timber to the market, the collection and study of windstorm damage information is critical for the understanding of wind effects on forests. Satellite remote sensors can provide the required information in a timely and reliable way.

Remote sensing for windblow damage assessment

Earth observation data has been widely used to rapidly detect disturbances and damage to forests at a variety of spatial scales. Space-borne satellite imagery is well suited for these tasks as new images are regularly acquired and the synoptic view offered by satellite data facilitates large area assessments. For instance, the European Forest Fire Information System (EFFIS) uses daily updated satellite data to identify and map wildfire and forest damage across Europe (Sedano et al. 2012). Similarly, satellite data has been used to quantify the extent of windstorm in forests. Wind damage can be analysed and assessed over large areas in a timely and cost effective manner by using satellite sensor imagery in combination with spatial analysis as provided by Geographical Information Systems (GIS). Nelson et al. (2009) combined Landsat data and stand inventory records from the Forest Inventory and Analysis (FIA) program to assess the effects of a catastrophic windblow event in northern Minnesota, USA and achieved an overall accuracy of 90% of the image-based damage classification map product. In addition, they provided estimates of total volume that was lost during the storm event. Jonikavičius and Mozgeris (2013) applied a similar approach using multi-temporal Landsat imagery, stand-wise forest inventory and a k-NN estimator to assess forest damage in Lithuania following a storm that occurred in August 2010.

In Europe, there has been extensive research into remote sensing techniques to assess the effects of the 2009 windstorm Klaus. Kempeneers et al. (2012) used low resolution, MODIS satellite data and a post-classification method to quantify the extent of windstorm damage in the Landes region of France. The same storm and study area was researched by Chehata et al. (2014), who applied a feature-selection and an image segmentation algorithm to high resolution, multi-spectral satellite imagery from Formosat-2 for the purposes of mapping the extent of the wind damage in the pine forests.

Aerial photography surveys tend to provide high levels of spatial detail, but they are typically not immediately available in the aftermath of a storm for large areas. However, when available, they are used for detailed windblow damage detection and assessment.

For instance, windblow gaps were detected by Jackson et al. (2000) from a multi-band Airborne Thematic Mapper (ATM) and a pixel-based maximum likelihood classifier. The approach successfully mapped forests, moorland and windblow gaps in Central Wales with an overall accuracy of 90%. Honkavaara et al. (2013) generated a post-storm Digital Surface Model (DSM) from high-flown orthophotographs in conjunction with a pre-storm LiDAR derived DSM to automatically map wind damage in Finnish forests.

Objectives

The aim of the rapid damage assessment defined by the Windblow Task Force was to better understand and quantify the wind damage affecting Irish forests and thereby improve decision making and support post-storm forest management. More specifically, the objectives of the rapid damage assessment were to:

1. estimate the extent and area of wind damage in Irish forests in the aftermath of Storm Darwin;
2. provide up-to-date, accurate spatial information that can assist decision makers in formulating relevant policies and aid forest companies with strategic planning. Information generated would aid forest managers/owners with, felling licence preparation, post-hazard relief activities and subsequent silvicultural management;
3. develop cost-efficient and reliable and highly automated methods that can assist the analysis in a timely fashion.

Materials and methods

Study area

While climatic records suggest that Storm Darwin was broadly a 1 in 20 year event, the categorisation as "worst in living memory" may be appropriate in the worst affected areas (McGrath 2015). The frequency and ferocity of the 2014 storm events, compounded by waterlogged soils on many sites, lead to extensive windblow. While initial estimates put the area damaged at less than 1% of the total forest area, locally the damage was severe, with significant volumes of roundwood impacted. The most severe Storm Darwin wind and associated forest wind damage was experienced in Galway, Clare, Limerick, Kerry and Cork but also included coastal areas in the south and northwest. Preliminary assessments of the damage immediately after the storm by the Windblow Task Force produced only a rough estimate of the amount and spatial location of damaged stands. It was estimated that area of wind damaged forest amounted to approximately 8,000 ha with the main concentration of damage occurring in Munster and south Leinster (Figure 2). The extreme west to northwest gusty winds behind the storm centre caused the majority of windblow. The strong gales and damage was also notable in regions around the M7 motorway corridor from Limerick to Dublin.

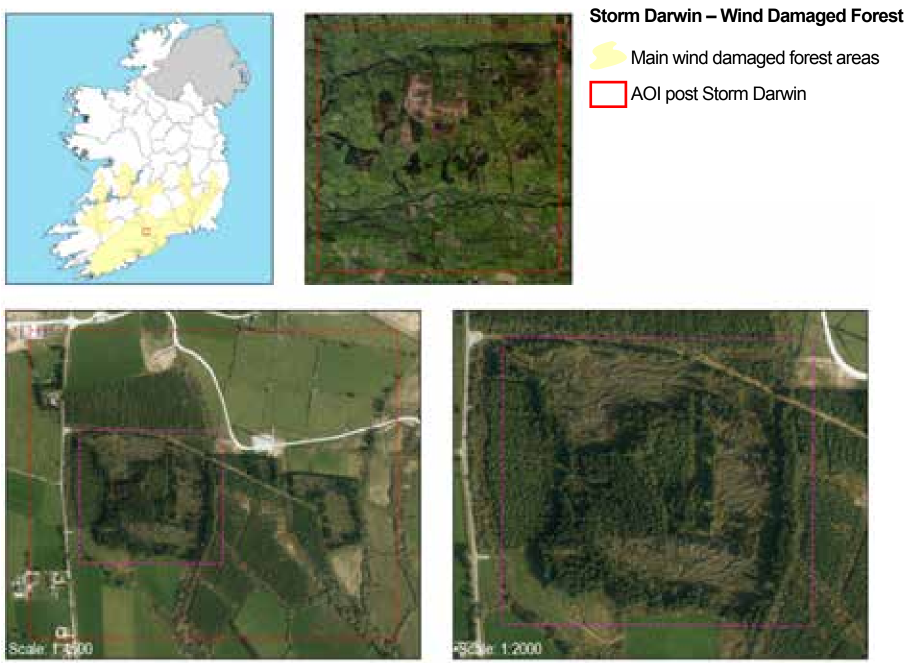

Figure 2: *Figure 2 Overview of main wind damaged forest areas following Storm Darwin with an example of post storm event forest damage near Ballyduff, (orthophoto 21st/22nd April, 2014, © BlueSky/Ordnance Survey Ireland).*

Data

Given the fact that there are many options that could potentially be used for the purposes of mapping the wind damage, it was necessary to identify data sources that could be realistically acquired within the time-frame of the project, available budget and meet the technical specifications. In the immediate aftermath of the storm, a number of data sources were critically evaluated based on the following criteria:

1. the feasibility to rapidly acquire data across the entire island;
2. quality of the data in terms of spatial resolution (image detail) and spectral resolution (information content);
3. total cost per unit area; and
4. health and safety considerations.

Aerial photography and Airborne Laser Scanning/LiDAR data would have been the optimal choice for detailed mapping, but they would have been too expensive for national coverage and it would have been unrealistic to acquire the data within the time-frame. Similarly, data acquired from Unmanned Airborne Vehicles (UAVs/

drones) would have provided imagery with high spatial resolution, but the cost and time in acquiring data across the country would have been prohibitive.

Space-borne satellite imagery was therefore considered as the most viable option for the purposes of the project.. A thorough evaluation of satellite data products were evaluated for the purposes of the project, which included Landsat, SPOT, Disaster Monitoring Constellation (DMC) and Indian Remote Sensing (IRS). The criteria that were used during the evaluation focussed on likelihood of cloud-free image data capture, cost, sensor specifications to meet the project requirements and availability of post-storm sample imagery. It was concluded that satellite sensors that form part of constellations and have the ability to be pointed are more suited in these instances. Consequently, the RapidEye constellation was identified as the most suitable data source in terms of:

1. image data quality - spectral resolution and spatial resolutions;
2. cost per unit area, and;
3. flexibility in terms of data acquisition.

This latter point is particularly pertinent to Ireland, where cloud-cover hampers the operational use of space-borne satellite data from sensors that are in fixed orbit. The ability of RapidEye to "tilt and point" in order to capture imagery increases the chances of acquiring cloud-free data.

RapidEye

The RapidEye system is a constellation of five identical space-borne sensors that are operated by Planet (previously known as Planet Labs/Blackbridge). The five satellites are located in a sun-synchronous orbit at 630 km. The sensors capture image data across the five following spectral bands:

- blue (440 – 510 nm)
- green (520 – 590 nm)
- red (630 – 685 nm)
- red edge (690 – 730 nm)
- near infra-red (760 – 850 nm)

The satellite's image pixel size is 5 m and each image tile is 25 × 25 km representing an area of 625 km^2. Each satellite sensor revisits the same location on the Earth's surface every 5 days, but RapidEye has the added flexibility of being capable of being programmed to tilt and capture data off its orbit. This unique benefit permitted data to be captured during cloud-free periods in April 2014. A subset of a RapidEye satellite image scene acquired over County Clare is provided in Figure 3. The cost of each image tile was €625, which is equivalent to €0.01 ha^{-1}.

Figure 3: *False-colour composite RapidEye satellite image acquired over Slieve Aughties, Co. Clare.*

Aerial photography

Three additional aerial datasets were used as part of the rapid damage assessment and specifically the quality assurance/quality control aspects of the analysis. These included: (1) aerial photography acquired by Ordnance Survey Ireland (OSi) during the period of April 2014 in the area of Rockchapel covering an extent of 40 km^2; (2) Digital Globe (Bing) aerial photography acquired between 2011-2013 accessed via a Web Map Service (WMS); (3) Coillte reconnaissance flight surveys over key areas considered to be affected by the storm. This latter dataset was used in conjunction with field inventory and verification subsequently digitally mapped by the Coillte GIS team.

Forest vector databases

The Forest Service's Forestry12 vector database and Coillte's Sub-compartment database were both used in this analysis. The Forestry12 dataset was used to mask the satellite imagery and to remove all satellite image pixels that were outside of the vector database. This reduced the computational area and image processing time quite significantly and ensured that analysis was focussed on only public and privately owned forests.

Methods

For the purposes of the project, it was agreed by the Ministerial Task Force that catastrophic wind damage would be assessed and quantified from the satellite data. In the context of this project, catastrophic wind damage related to gaps that were greater than 0.5 ha and where the trees were levelled. The project did not seek to map single tree damage or gaps smaller than 0.5 ha, or areas where there was partial blow (i.e. trees were still standing at an angle of 45 degrees). Furthermore, it did not map areas that would have been included as part of a forest management felling prescription, i.e. "squaring off" areas.

The processing and analysis of the RapidEye satellite data was carried out on a Workstation running Linux (Ubuntu 12.04 LTS) using free, open-source geospatial tools that included:

- the Geospatial Data Abstraction Library (GDAL) (http://gdal.org) that was used for the pre-processing of satellite imagery and vector datasets (e.g. coordinate transformation, image masking);
- Orfeo Toolbox (OTB) for the calculation of textural image features and vegetation indices;
- pktools (http://pktools.nongnu.org) was used for the supervised image classification using a Support Vector Machine (SVM), accuracy assessment and post-processing of the image classification (sieving and filtering);
- QGIS (http://qgis.org) was used for the visualisation and interpretation of image and vector datasets as well as for map production and analysis;
- R Statistics (http://r-project.org) was used for statistics and reporting.

In total, 224 individual image scenes were acquired for the project; in some instances, if the cloud cover was too high, multiple image scenes were delivered by the data providers for the same area. Given the number of scenes involved, a semi-automated processing workflow was developed as a Unix shell script to facilitate the processing within the given timeframe. Figure 4 provides an overview of the processing workflow that covers the pre-processing, image classification and quality control of the output products.

For the purposes of this project, the RapidEye Level-3A products were used, which are ortho-rectified tile products and have radiometric, geometric and terrain corrections. The images were all ortho-rectified by Planet (Blackbridge) using the Landsat-7 GCP model (Personal communication, 2014). Consequently, no further changes to the image geometry were carried out as part of the pre-processing steps. Furthermore, given the strict timelines, the images were not atmospherically corrected and as such the Digital Numbers were used for the analysis. Overall, the RapidEye imagery achieved a cloud cover of less than 20%. In cases where this was exceeded, a

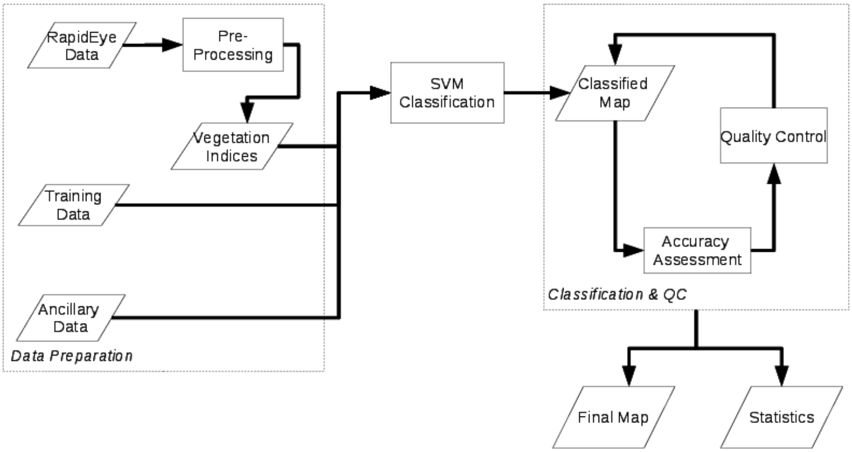

Figure 4: *Windblow rapid damage assessment workflow.*

subsequent satellite image scene was delivered of the affected area. For the purposes of the analysis, a cloud mask (including haze) was generated by photo-interpretation in conjunction with the Unusable Data Mask (UDM) file provided with the Level-3A product.

A number of image features were generated from the satellite data that were used as explanatory variables to improve the discrimination between damage classes. These included the:

- Normalised Difference Vegetation Index (NDVI), which is defined as a ratio between the Near Infra-Red (NIR) and Red (R) spectral bands :
  NDVI = (NIR – R) / (NIR + R) ;
- Normalised Difference Red-Edge Index (NDRE) is similar to the NDVI, but instead of using the NIR it relies on the Red-Edge band:
  NDRE = (RE – R) / (RE + R);
- a set of Haralick Textural features including entropy and standard deviations (Haralick et al. 1973).

It should be noted that the vegetation indices follow a phenological pattern and that the dates of the acquired RapidEye data did not correspond with the peak of the growing season. This may have resulted in a relatively less accurate classification than would have been the case had the RapidEye data been acquired in May or June. However, a pragmatic decision was made to use these indices in the context of the analysis as they can nonetheless be used to discriminate between stands affected by windblow from those that were not; that being the purpose of the exercise, rather than the calculation of NDVI or NDRE for the purposes of phonological analysis.

As such, the explanatory variables for the image classifier consisted of the five spectral bands from the RapidEye data, two Vegetation Indices (NDVI/NDRE) and two Haralick features (standard deviation and entropy). This set of variables formed the input data for the supervised image classifier that was implemented using a Support Vector Machine (SVM) from the pktools packages (McInerney and Kempeneers 2014). A SVM classifier is a supervised machine learning algorithm that can be used for image classification. SVM classifiers have their roots in Statistical Learning Theory and have gained prominence because they are robust, accurate and are effective even when using a small training sample (Gidudu et al. 2007). They are non-parametric and therefore no *a priori* assumptions are made about the distribution of the probability density functions of each each class. SVMs are based on the idea of finding the optimal hyperlane (line) that gives the best separation between two classes in a training dataset (Hastie et al. 2001). The image classification was defined to include two classes:

- standing (un-damaged forests),
- wind damaged forests.

Supervised classifiers require a “reference dataset” that consists of a number of training sites that are considered to be representative of each class. These training sites are manually photo-interpreted and digitised across the image and then the spectral signature (spectral information from the satellite imagery) is extracted for each labelled training site. The image classifier uses these training features to identify and classify the satellite image based on the spectral information.

The image classifier produced an intermediate product, which was cross-checked as part of a quality control process, with Bing/Digital Globe aerial photography. This process was necessary in the absence of pre-storm RapidEye data and provided a facility to determine if a change had occurred or not during the intervening period.

Results

The results from the automated mapping highlighted areas that were most severely hit included areas of Counties Kerry, west Cork, Limerick, Tipperary and Clare. A heat-map was generated from the damage dataset that provided an overview of the damage across Ireland. Examples of the mapped output is provided in Figure 5 for areas that were windblown in Co. Clare. The delineation is based on a vectorisation of the raster classification, which produces the step-like boundary. Generalisation algorithms can be applied to produce a smoothed linear boundary.

Accuracy Assessment

The confusion (error) matrix for the image classification based on a random sample of points generated within the extents of the OSi aerial photography in Co. Limerick

Figure 5: *Automatic delineation of windblow damage from RapidEye satellite imagery.*

(Table 2). Each point represented the centre of a synthetic 0.04 ha plot, which was photo interpreted in a GIS. The Digital Globe orthophoto dataset used reflected the pre-storm situation and was used for comparison purposes in the areas coinciding with the OSi orthophotography. The synthetic plots were based on the interpretation of a 4 × 4 window of pixels around the point. The class assigned to the point (synthetic plot) was based on the majority of the class interpreted from the aerial photography. This approach alleviated the issues associated with the difficulty in interpreting single points that occur on boundaries. The validation dataset (n = 262) was then compared to the output of the image classification to provide an overall accuracy of the classification

Table 2: *Error matrix based on classification output (forest area in ha).*

	Reference		
	Undamaged	**Damaged**	**Total**
Undamaged	193	6	189
Damaged	26	37	63
Total	219	43	262
Overall accuracy		83.33 (+/- 2.7)	

	Undamaged	**Damaged**
Producer' accuracy	88.12 (±3.14)	86.05 (±10)
User's accuracy	96.83 (±1.48)	59.00 (±9.63)
Kappa Index of Agreement	68%	

output and a producer's and user's accuracies. The producer's accuracy (PA) refers to the omission estimates, while the user's accuracy refers to the commission estimates.

The overall accuracy of the rapid damage assessment dataset based on the study area in Athea, Co. Limerick was 83.3%. The producer's accuracy for the undamaged and damaged classes were 88 and 86% respectively, while the user's accuracy (commission errors) were lower for the damage class at 59%. These commission errors were largely attributed to miss-classifications due to cloud-shadow, shadows cast by trees due to low sun-angles and existing gaps within the forest. Validation was not considered for the remainder of the country because of tight project timelines for completion of the project. In addition, Co. Limerick was representative of the damage experienced in other countries. Subsequent wind damage field surveys and site level damage mapping by Coillte showed that his was the case on the ground.

Summary statistics

A summary of the wind damage mapped by county is provided in Table 3. It is evident from the table that the majority of the damage occurred in the public forests (Coillte forest area) with Counties Clare, Cork, Limerick and Kerry most severely hit, which is also illustrated by the heatmap of wind damage across the country (Figure 6).

Table 3: *Cumulative windblow damage by county for public and private forests as detected from the Rapid Damage Assessment.*

County	Forest area (ha)	Damage private (ha)	Damage public (ha)	Percentage
Clare	52,000	579	884	2.81
Cork	83,000	364	1,572	2.33
Cavan	16,000	0	14	0.09
Carlow	8,000	3	101	1.30
Donegal	56,000	5	56	0.11
Galway	59,000	56	114	0.29
Kilkenny	19,000	72	268	1.79
Kerry	53,000	501	944	2.73
Longford	8,000	0	2	0.03
Leitrim	25,000	1	12	0.05
Limerick	26,000	354	958	5.05
Laois	25,000	14	93	0.43
Mayo	51,000	4	17	0.04
Offaly	24,000	0	6	0.03
Sligo	20,000	1	15	0.08
Tipperary	48,000	232	552	1.63
Waterford	26,000	8	179	0.72
Wicklow	35,000	2	66	0.19
Wexford	13,000	2	269	2.08
Total	**647,000**	**2,198**	**6,122**	**1.29**

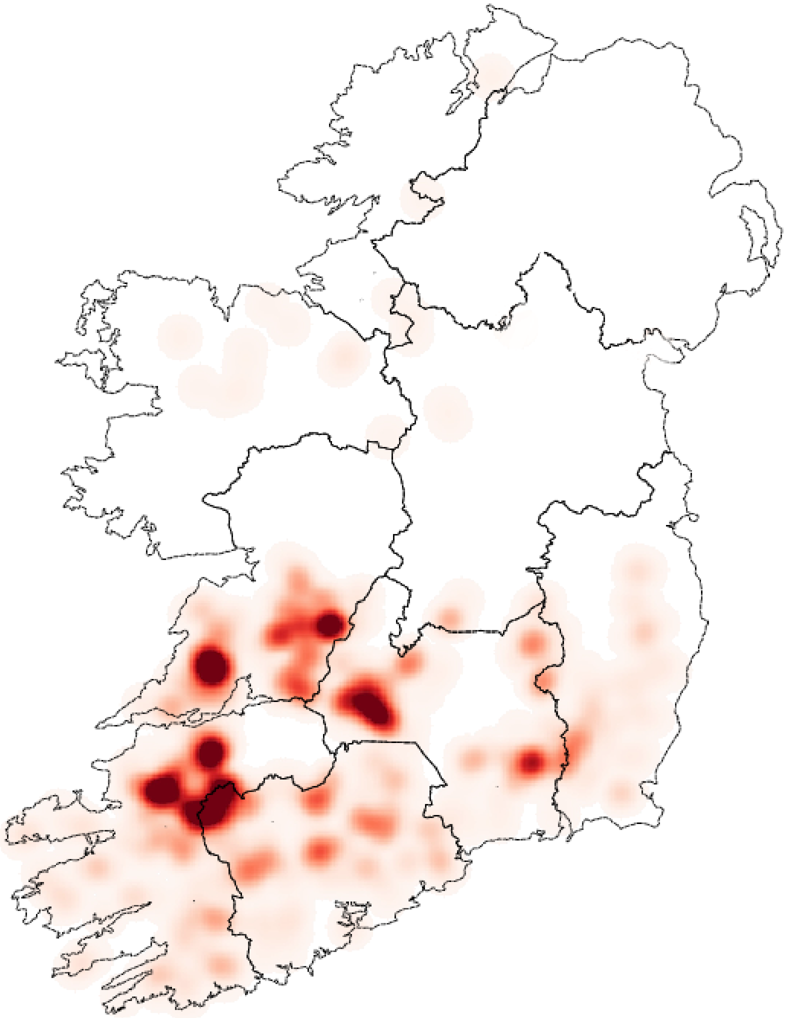

Figure 6: *Heat map of wind damage across the estate. Darker red indicates more intense damage.*

Discussion

Quantification of spatial and temporal changes in forest cover is an essential component of forest monitoring programs and space borne passive optical or NIR remote sensing has been an important tool for mapping the extent and location of large-scale forest disturbances. However, frequent extensive cloud cover over mid-latitude coastal regions of the Northern Hemisphere, such as Ireland, has historically presented a challenge to optical remote sensing of these areas (O'Connor et al. 2008, Serbin and Green 2015). The 5-satellite RapidEye constellation provided the required earth observation data in a flexible, timely and reliable way and showed the utility of accessing a multiple sensor constellation service for operational use at a latitude where almost year round cloud cover and long-time satellite revisit times has historically been a barrier to national scale remote sensing initiatives.

The delivery of a national Irish wind damage map product after only a 12-week period is testament to the operational viability of the approach and demonstrates that wind damage can be analysed and assessed over large areas in a timely and cost effective manner by using satellite sensor imagery in combination with spatial analysis as provided by Geographical Information Systems (GIS). The digital wind damage maps of windblown areas are currently available on the industry mapping system (iNET) provided by the Forest Service in the Department of Agriculture, Food and the Marine to registered foresters operating the Department's Schemes. This national wind damage "map layer" provides forest managers, owners, and the Forest Service with much needed information for forest management planning, harvest scheduling, timber processing, reforestation and the regulation of felling activities.

A damage classification of wind damaged forest was not considered for the work undertaken by the consortium. Damage classification typically requires assignment of a continuous damage measure into discrete damage classes (e.g. Olthof et al. 2004, Jonikavičius and Mozgeris 2013). In the context of this rapid damage assessment, wind damage was defined as gaps in the canopy cover greater than 0.5 ha and where the trees were levelled. The project did not seek to map single tree damage or gaps smaller than 0.5 ha, or areas where there was partial blow (i.e. trees were still standing at an angle of 45 degrees). In future, it would be of benefit to identify those areas where partial blow is also present and classify the degree of wind damage so that a more comprehensive estimate of wind damaged areas might be produced.

Copernicus Emergency Management Service (© European Union 2016) (EMS) provides information for emergency response in relation to different types of disasters, including meteorological hazards, geophysical hazards, deliberate and accidental man-made disasters. Copernicus EMS consists of the Mapping Service and of the Early Warning System (floods). Contact with Copernicus was initiated as part of the Task Force response to the wind damage caused by storm Darwin. Wind damage maps and data products were subsequently provided by Copernicus for three 10 km^2 areas centred around Templeglantine, Co. Limerick and Kilmaley, Co. Clare (Copernicus Emergency Management Service (© European Union 2014, EMSR077) to the Forest Service in the Department of Agriculture, Food and the Marine (DAFM). The products from the Copernicus EMS were useful in demonstrating the capacity of earth observation data to identify and quantify areas of wind damage in a short time frame and facilitated verification of at least some of the felling licence applications to the Forest Service for wind damage within the mapped areas. Unfortunately, the Copernicus EMS could not meet the basic requirement for a nationally consistent wind damage assessment product and so the decision was made by the consortium to proceed with RapidEye damage assessment as carried out by Coillte.

Increasing storm intensity accompanied by heavier rainfall leading to more saturated soils together with an increasing and ageing forest stock are expected to result in substantial increases (at least double) in forest damage across Europe by the end of the century (Gardiner et al. 2010). Climatic simulations carried out by Gleeson et al. (2013) for Ireland showed an overall increase (0 to 8%) in the energy content of the wind for the future winter months and a decrease (4 to 14%) during the summer months. A recent study with a very high resolution version of the EC-Earth model (Haarsma et al. 2013) also suggests an increase in the frequency of extreme wind storms affecting Western Europe in future autumn seasons due to global warming. This will translate into an increased risk of storm damage, flooding and soil saturation with associated risk of damage to Irish forests.

There is no consistent recording and reporting system for wind damage across Europe or for reporting damage from different hazards. This leads to uncertainties in relative levels of wind damage within different parts of Europe and in comparing the importance of hazards (Gardiner et al. 2010). The Forest Service (DAFM) are currently members of the European Horizon 2020 funded DIABOLO project which will provide improved information related to forest disturbances (e.g. forest fires, storm, drought, insect outbreaks) and their impacts using earth observation data. Working Group 4 of the DIABOLO project aims to provide European scale harmonised data on forest disturbances and also a near real time forest disturbance monitoring service via a European Forest Disturbance Monitoring System (EFDMS). The experience and lessons learned from the Rapid Damage Assessment of Windblow post storm Darwin will help to steer and improve the design, development and methodology implemented for the EFDMS, making its application more relevant in an Irish context. In addition, by adoption of a test site in Ireland, DIABOLO will further strengthen the capacity for both assessing risks and monitoring forest disturbances such as wind damage on a pan-European scale and at regional levels.

Conclusion

It has been well established that space borne passive optical or NIR remote sensing is an important tool for mapping the extent and location of forest disturbances. The results of this study demonstrate the applicability of remote sensing data in collecting windstorm forest damage data in Ireland. A reliable, objective, digital methodology for forest change detection using RapidEye imagery was developed and applied successfully in an Irish forest context. The supervised classification, vegetation indices (NDVI/NDRE) and textural analysis methods adopted were well suited for emergency mapping and allowed for accurate and timely assessment of windstorm damage, meeting the objective of windblow Task Force in terms of identifying damage locations.

The 5-satellite RapidEye constellation provided the required image data in a flexible, timely and reliable way. It demonstrated the benefit of accessing a multiple sensor constellation service for operational use at a latitude and during a season where high cloud cover has historically been a barrier to national scale remote sensing surveys. Employing an open source and highly automated remote sensing methodology was particularly effective given the short timeframe to produce the national windblow map data, which would not have been possible with the sole use of a ground-survey.

The DAFM experience with Copernicus EMS has shown that while it is not applicable for national scale surveys, the service will be of significant future value in cases of localised forest damage and or related emergencies (e.g. upland fires/forest fires or localised wind damage).

Finally, the spatial data generated in the national wind damage map can be used in a research context and over the longer term in policy development for improved forest management, improved forest design (e.g. cultivation practices, species choice) and damage mitigation measures to increase the resilience of Irish forests to future storms.

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References

Anon. 2016. Coillte invoiced sales volumes from windthrow sales proposal 1992–2015. Unpublished.

Chehata, N., Orny, C., Boukir, S., Guyon, D. and Wigneron, J.P. 2014. Object-based change detection in wind storm-damaged forest using high-resolution multispectral images. *International Journal of Remote Sensing* 35: 4758–4777.

Copernicus Emergency Management Service. 2014. EMSR077. Available at http://emergency.copernicus.eu/EMSR077 [Retrieved September 2015].

DAFM. 2013. *National Forest Inventory – Republic of Ireland – Results. Covering the National Forest Inventory, 2009 to 2012*. Johnstown Castle, Co. Wexford. pp. 265.

Gallagher, G.J. 1974. Windthrow in state forests in the Republic of Ireland. *Irish Forestry* 31: 154–167.

Gardiner, B., Blennow, K., Carnus, J.M., Fleischner, P., Ingemarson, F., Landmann, G., Lindner, M., Marzano, M., Nicoll, B., Orazio, C., Peyron, J.L., Reviron, M.P., Schelhaas, M., Schuck, A., Spielmann, M. and Usbeck, T. 2010. *Destructive storms in European Forests: Past and Forthcoming Impacts*. Final report to European Commission - DG Environment. European Forest Institute, Joensuu, Finland. p. 138.

Gidudu, A., Hulley, G. and Marwala, T. 2007. *Classification of Images using Support Vector Machines*. arXiv: 0709.3967v1, Cornell University Library.

Gleeson, E., McGrath, R. and Treanor, M. (Eds). 2013. *Ireland's Climate: the Road Ahead*. Dublin: Met Éireann. ISBN 978-0-9521232-6-2. p 101.

Haarsma, R. J., Hazeleger, W., Severijns, C., de Vries, H., Sterl, A., Bintanja, B., van Oldenborgh, B. J. and van den Brink, H.W. 2013. More hurricanes to hit western Europe due to global warming. *Geophysical Research Letters* 40: 1783–1788.

Hastie, T., Tibshirani, R. and Friedman, R. 2001. *The Elements of Statistical Learning – Data Mining, Inference and Prediction*. Springer.

Haralick, R., Shanmugam, K. and Dinstein, I. 1973. Textural features for image classification. *IEEE Transactions on Systems, Man and Cybernetics* 3: 610–622.

Honkavaara, E., Litkey, P., Nurminen, K. 2013. Automatic Storm Damage Detection in Forests Using High-Altitude Photogrammetric Imagery. *Remote Sensing* 5: 1405–1424.

Jackson, R.G., Foody, G.M. and Quine, C.P. 2000. Characterising windthrow gaps from fine spatial resolution remotely sensed data. *Forest Ecology and Management* 135: 252–260.

Jonikavičius, D., Mozgeris, G. 2013. Rapid assessment of wind storm-caused forest damage using satellite images and stand-wise forest inventory data. *iForest* 6: 150-155.

Kempeneers, P., Sedano, F., Strobl, P., McInerney, D. and San-Miguel, J. 2012. Increasing Robustness of Postclassification Change Detection Using Time Series of Land Cover Maps. *IEEE Transactions on Geoscience and Remote Sensing* 50: 3327–3339.

McGrath, R. 2015. *Impact of Storm Darwin on Ireland: Description of the Event and Assessment of Weather Forecasts*. Met Éireann Technical Note 64.

McInerney, D. and Kempeneers, P. 2014. *Open-source Geospatial Tools: Applications in Earth Observation*. Springer. Pp. 358 ISBN-10: 331901823X.

Mitchell, S.J. 2013. Wind as a natural disturbance agent in forests: a synthesis. *Forestry* 86: 147–157.

Nelson, M.D., Healy, S.P, Moser, K.W. and Hansen, M.P. 2009. Combining satellite imagery with forest inventory data to assess damage severity following a major blowdown event in northern Minnesota, USA. *International Journal of Remote Sensing* 30: 5089–5108.

Ní Dhubháin, Á. 1998. The influence of wind on forestry in Ireland. *Irish Forestry* 55: 105–113.

O'Connor, B., Dwyer, N. and Cawkwell, F. 2008. Satellite remote sensing as a tool for monitoring vegetation seasonality. *Proceedings of the Remote Sensing and Photogrammetry Society Conference 2008*. "Measuring change in the Earth system". University of Exeter, 15th–17th September 2008. pp 1–4.

Olthof, I., King, D.J. and Lautenschlager, R.A. 2004. Mapping deciduous forest ice storm damage using Landsat and environmental data. *Remote Sensing of Environment* 89: 484–496.

Sedano, F., Kempeneers, P., Strobl, P., McInerney, D. and San-Miguel, J. 2012. Increasing spatial detail of burned scar maps using IRS-AWiFS data for Mediterranean Europe. *Remote Sensing* 4: 726–744.

Serbin, G. and Green, S. 2015. *Optical Remote Sensing of Permanent Deforestation in Ireland*. 9th Irish Earth Observation Symposium. Irish Earth Observation Symposium. National University of Ireland. Galway. 21st–22nd October 2015.

The psychological and physical impacts of spending time in forests: a case study of two forests in Ireland

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Abstract

The overall aim of this study was to investigate the psychological and physical health/well-being effects of spending time in forests, and the role that the species composition of the forests plays in these effects. The effects were assessed by a simple questionnaire survey to 179 visitors to two adjacent forests; a conifer plantation forest and a broadleaf plantation forest. The immediate psychological effects from spending time in forests were also assessed by a mood test, and the longer-term psychological and physical health impacts of forest use were explored by comparing the results of the survey of forest visitors with that of a national survey. The results indicated that the main psychological well-being benefits experienced by forest users were "mental relaxation" and "enjoyment and fun". Significant improvements in mood immediately after a walk in the forest were exhibited by the respondents, but the species composition of the forests was not shown to influence the improvements. It was also revealed that forest visitors engaged in greater levels of physical activity than the general population, but there was no correlation found between forest users' physical activity level and frequency of forest use. It was recommended that further research should aim to make use of large-scale surveys of a random sample of the population including visitors and non-visitors to forests.

Key words: *Health benefits of forests, mood tests, forest therapy, species composition of forests, longer-term physical and psychological health impacts.*

Introduction

Globally, forests and trees are believed to supply a wide range of services which benefit human health and well-being. In developed societies, research into the benefits of forests for human health and well-being has focused on the provision of psychological restoration and enhancement of physical activities and social interaction due to an increasing number of social needs such as increasing levels of obesity, chronic lifestyle-related diseases, mental illness and disorders such as anxiety and depression (Hartig et al. 2014). The restoration effects have become the target of research interests since the 1970s with the establishment of two main theories; Attention Restoration Theory which focuses on the elimination of mental fatigue and the improvement of cognitive functions by contact with nature (Kaplan 1983, Kaplan and Kaplan 1989) and Stress Reduction Theory which focuses on a human's positive emotional and psychological reactions to nature (Ulrich 1983, Ulrich et al. 1991).

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Several empirical studies have been conducted to explore the psychological and physiological effects of exposure to nature. The evidence suggests that spending time in green spaces such as forests and urban greens, or even viewing a landscape from a window has restorative effects on people. These effects include improvement in mood and emotional status (e.g. Peacock et al. 2007), increase in concentration and attention (e.g. Berman et al. 2012), strengthened immune systems (e.g. Li et al. 2008), and lowered blood pressure and stress hormone levels (e.g. Tsunetsugu et al. 2013). However, little is known about the health benefits gained from spending time in forests compared with those experienced from spending time in other natural environments such as urban parks, hills, grassland or agricultural land (Bowler et al. 2010).

Some studies have also reported that accessible green spaces could improve people's physical health by enhancing people's motivation for physical exercise (e.g. Richardson et al. 2013). Other studies found that exposure to wood essential oils, "phytoncides", increased the number and the activity of natural killer cells which are an important component of the human immune system (e.g. Li et al. 2008).

In some countries, forests are actually used as a part of health care in collaboration with medical institutions. For example, in Germany, nature walks are included in the traditional therapy, "kur" ("course of treatment") along with herbal remedies and mud baths (Maretzki 1987). In Japan, "forest bathing" (spending time in forests) is regarded as preventive medicine, with medical professionals recommending forest walks to people who have been diagnosed as overstressed or with symptoms such as high blood pressure or high cholesterol (Forest Therapy Society 2013).

In the UK, there have been a number of health projects initiated by the Forestry Commission, local councils or local communities including projects targeting the sedentary, disabled, elderly, minority groups, the socially deprived and those with mental health problems. For example Forestry Commission Scotland (2015) currently has a WIAT (Woods in and around towns) programme which aims to tackle the barriers people face visiting woodlands. In Ireland, several health promotion programmes have been run in tandem with the establishment of walking routes. Coillte (The Irish Forestry Board) provides more than 150 recreation sites across the country and also runs pilot programmes including a forest walk for people who are experiencing mental ill-health (Iwata et al. 2016).

In spite of the range of previous research and case studies, a full understanding of the mechanisms by which people experience the psychological effects from contact with green spaces, including forests, has yet to be established. For example, little is known about the elements or condition of forests, the kind of activities and frequency of use, or the types of users which would lead to, or experience, the greatest benefits. Also, most previous studies have focused on short-term effects, and longer-term effects have not been properly assessed (Bowler et al. 2010). Furthermore, perceptions toward forests and the relationship between forests and people could differ between different countries and cultures so that they might have different effects. With this in mind, we note that there have been no studies conducted in Ireland to investigate the relationship between people's health and spending time in forests with the exception of Iwata et al.'s (2016) study which explored the benefits for people suffering from mental ill-health of spending time in forests.

In this context this study was initiated with the aim to investigate whether forest visitors in Ireland experience short-term and long-term psychological and physical benefits from spending time in forests and to determine whether the species composition of forests influences these benefits.

Materials and methods

A survey of visitors to two adjacent forests, the Hell Fire Club and Massy's Estate was conducted. The Hell Fire Club[1] comprises a conifer plantation, mainly of Sitka spruce (*Picea sitchensis* (Bong.) Carr.) and larch (*Larix decidua* L.), although a small amount of beech (*Fagus sylvatica* L.) is present. There are about 4.5 km of forest roads and trails present on the site. The forest is situated on a hill and there is a view of Dublin city from an altitude of 383 m. A car park, situated beside the entrance of the trail, has parking spaces for approximately 60 cars. Massy's Estate is predominately a broadleaved plantation including species such as beech (*Fagus* spp.), oak (*Quercus* spp.), lime (*Tilia* spp.), horse chestnut (*Aesculus hippocastanum* L.), sycamore (*Acer pseudoplatanus* L.) and ash (*Fraxinus excelsior* L.) with a rich ground flora in the understorey. It has about 1.5 km of forest trails. Other features found on the site include a stream, small waterfalls and ponds. The two forest sites are located 14 km from the centre of Dublin. Both forests are owned by Coillte, and information about them can be found on the Coillte Outdoors official website as well as other tourist guides. The sites were chosen for study as they are known to be very popular sites for visitors (Magner 2011) and they differ in their species composition. Also, their close proximity to each other meant that they had the same characteristics in terms of accessibility, distance from the city centre and availability of facilities such as a car park.

Questionnaire survey

A survey of visitors to the two sites was conducted on three Sundays in October (2013), November (2013) and January (2014) (Table 1). On the first two dates the survey took place in a car park beside the Hell Fire Club which is also used by visitors to Massy's Estate. Two surveyors waited at the car park, and asked visitors to complete a questionnaire at their cars. The surveyors attempted to approach as many visitors as possible before they

[1] A ruin on top of the hill, which was originally a hunting lodge, became infamous in the 18th century for being used as a base for the Dublin branch of the Hell Fire Club; a club where "wild young Dublin gentlemen" would congregate for "drunken revelry" (Magner 2011, p. 207).

started to walk, but because of the numbers of visitors and need to explain and collect the survey sheets, some of the visitors were missed. Also some of the visitors refused to participate, especially those who had small children with them (Table 1). As fewer questionnaires were collected from people visiting Massy's Estate during the first two survey days, the third survey was conducted at the entrance to Massy's Estate.

The questionnaire addressed the following themes:

Visitation pattern

Respondents were asked to identify the forest they planned to visit on the day of the survey. They were also asked to identify how often they visited the forests and the distance they travelled to do so.

Forest features of importance

Respondents were asked to rank the importance to them of nine features of the forest they planned to visit (i.e. Conifer trees, Great view, Ruin of Hell Fire Club, Size of the forest, Parking area, Broadleaf trees, Stream, Plants and animals, Smells and atmosphere) from 1 (Not at all) to 6 (Extremely). Data from those who visited both forests and those who answered "Not sure" were excluded from the analysis in order to investigate the differences between the two forest sites.

Well-being benefits

The well-being benefits gained from a forest visit were also determined. The benefits listed in the questionnaire were those identified by O'Brien and Morris (2014) in a previous study of the well-being benefits that people can gain from trees, woods and forests.

Mood change

Immediate mood changes in the visitors arising from a forest walk were assessed using the Positive and Negative Affect Schedule (PANAS). PANAS is a frequently

Table 1: *Survey details including prevailing weather conditions and the response rate achieved.*

	Day 1	Day 2	Day 3
Date	26th Oct 2013	3rd Nov 2013	19th Jan 2014
Weather	Cloudy, some rain, some sunshine	Sunny	Sunny
Temperature	10-12 °C	7-9 °C	5-6 °C
Survey time	10:00 ~ 17:30	10:00 ~ 15:00	10:00 ~ 17:00
Survey site	Hell Fire Club car park	Hell Fire Club car park	Massy's Estate entrance
Questionnaires completed	72	53	54
Response rate	70%	55%	90%

used methodology to indicate mood changes after a treatment (Watson et al. 1988) and it has been used in some studies related to the psychological effects of spending time in nature (e.g. Berman et al. 2008, 2012). In this study, the forest visitors were asked to fill in a one-page worksheet for the PANAS mood test before and after the walk. The PANAS worksheet typically consisted of words that describe different feelings and emotions, in which some were for measuring Positive Affect (PA) and others for measuring Negative Affect (NA) (Table 2). Each word was scored on a 6-point scale ranging from 1 (not at all) to 6 (extremely) to indicate the extent to which the participant was experiencing this feeling when they were completing the sheet.

High PA was defined as a state of "high energy, full concentration, and pleasurable engagement" and low PA is a state of "sadness and lethargy". High NA was characterised by "subjective distress and unpleasable engagement that subsumed a variety of aversive mood states, including anger, contempt, disgust, guilt, fear, and nervousness" and low NA was a state of "calmness and serenity" (Watson et al. 1988 p. 1063).

Socio-demographic characteristics

Some socio-demographic characteristics of respondents were recorded including their age; employment status; family status; education level and marital status.

Level of physical activity

Respondents were asked a number of questions relating to their involvement in physical activity in the seven days prior to the survey. These questions were the same as those included in the International Physical Activity Questionnaire Short Form (IPAQ 2005). This is a standardized method which facilitates the quantitative measurement of physical activity levels by computing a continuous measure of the volume of activity computed by weighing each type of activity by its energy requirements, i.e. MET-min per week[2]. The level is categorised into Low, Moderate and High based on criteria outlined in IPAQ (2005). The results for the forest visitors were compared to those recorded by Barry et al. (2009) who applied a similar methodology to a sample of the general population of the Republic of Ireland and Northern Ireland in their Survey on Lifestyle, Attitudes and Nutrition (SLÁN) in Ireland conducted in 2007.

Table 2: *Words used to indicate mood changes experienced by the visitors arising immediately after a forest walk (after Watson et al. 1988).*

Positive affect (PA) words	Negative affect (NA) words
Interested; Excited; Strong; Enthusiastic; Proud; Alert; Inspired; Determined; Attentive; Active.	Distressed; Upset; Guilty; Scared; Irritable; Ashamed; Nervous.

[2] The metabolic equivalent of task (MET), or simply metabolic equivalent, is a physiological measure expressing the energy cost of physical activities. MET-min per week = MET level x minutes of activity/day x days per week; typical MET levels: walking = 3.3 METs, moderate intensity exercise = 4.0 METs, vigorous intensity = 8.0 METs.

An estimate of the amount of exercise conducted by each respondent in different settings was calculated by multiplying the value of MET-minutes per week, by the proportion of the time each respondent spent exercising in the different settings. This made it possible to investigate the relative importance of forest settings for their exercise.

Mental health and social well-being

The mental health status of forest visitors and that of the general population of the Republic of Ireland and Northern Ireland was compared to determine if there were longer-term benefits of spending time in forests on human mental health. To do this, the same questions as used in the SLÁN study of 2007, referred to above, were used to assess the mental health and social well-being of respondents. Using the answers to these questions, mental health was assessed under two headings: positive mental health using an Energy and Vitality Index (EVI) (Ware et al. 1993) and psychological distress using a Mental Health Index-5 (MHI-5) (Ware et al. 1993).

Data analysis

A number of statistical tests were used to address the objectives of the study. To assess whether there was a significant change in mood arising from a forest visit a paired-sample t-test in SPSS v20 (IBM Corp. 2011) was conducted. The changes in the positive mood and negative mood were investigated separately, as is the norm (Watson et al. 1988). Additionally a one-way ANOVA in SPSS was used to investigate whether the extent of the mood changes varied significantly according to the forest that the respondent visited.

A chi-square test (Microsoft Excel) was used to investigate whether the level (three categories) of physical activity of the respondents to this survey and that of the Irish population differed significantly. Independent t-tests (Microsoft Excel) were conducted to determine whether the mental health (i.e. mean EVI and mean MHI-5) of the respondents to this survey and that of the Irish population differed significantly. A multiple regression analysis in STAT software (SAS Institute 2011) was used to investigate the most influential predictor variables for the level of physical activity and mental health status and to investigate the significance of frequency of forest use to these activity levels. The continuous variables of MET-min per week for the level of physical activities and EVI and MHI-5 for the mental health status were used as dependent variables. As independent variables, categorical variables including the frequency of forest use and socio-demographic characteristics (age, employment, number of children, education, income and marital status) were used. Many of the categories for these independent variables were re-coded as they had small numbers (Table 3). A Tukey-Kramer post-hoc test was conducted for the variables that were shown to be significant.

Table 3: *Socio-demographic characteristics used as independent variables in a multiple regression analysis to investigate the most influential predictor variables for the level of physical activity and mental health (figures in parenthesis refer to % of respondents).*

Variables	Code	Original categories
Age (years)	0	18 – 24 (3%), 25 – 34 (28%)
	1	35 – 44 (31%), 45 – 54 (22%)
	2	55 – 64 (13%), 65 – 74 (3%), 75 + (1%)
Employment status	0	Working full-time 30 hrs+week^{-1} (73%), Working 8-29 hrs week^{-1} (10%)
	1	Working less than 8 hrs week^{-1} (2%), Unemployed (2%), Home maker (2%), Other (2%)
	2	Retired from full-time job (5%)
	3	Student (4%)
No of children under 18	0	0 (56%)
	1	1 (10%), 2 (24%), 3+ (10%)
Level of education	0	Primary or equivalent (4%), Leaving Cert or equivalent (16%)
	1	Diploma or Certificate (25%), Postgraduate Higher Diploma / Masters (50%), PhD (4%)
Annual household income	0	<€190 wk^{-1}, €800/m or €10,000 yr^{-1} (1%), €10,000 – €19,000 yr^{-1} (4%), €20,000 – €29,999 yr^{-1} (8%), €30,000 – €39,999 yr^{-1} (9%), €40,000 – €49,999 yr^{-1} (7%)
	1	€50,000 yr^{-1} or more (37%)
Marital status	0	Married / in a civil partnership (69%)
	1	Separated (2%), Divorced (1%), Widowed (1%), Never married (27%)

Results

Pattern of visits to the Hell Fire Club / Massy's Estate

The Hell Fire Club and Massy's Estate are located immediately next to one another, hence the visitors could easily walk to both of the forests on the same day. On the day(s) the survey was completed 44% of the respondents planned to visit the Hell Fire Club and 47% planned to visit Massy's Estate, and the remainder were not sure.

The questionnaire conducted in Massy's Estate on the third day contained an additional open-ended question asking whether respondents had a particular reason(s) for choosing to walk in Massy's Estate instead of the Hell Fire Club. As shown in Table 4, some people valued the features of the natural environment such as the deciduous trees and river; whereas other people valued its topography compared to that of the Hell Fire Club which made walking easier especially for little children. Some made the choice based purely on habit.

The average straight-line distance between the respondent's residential area and the car park of the Hell Fire Club was 8.3 km, and the average estimated time taken for travel was 15 minutes. The majority of the respondents lived within 5 to 10 km of the forests which would require 11-20 minutes driving. Respondents visited the forest with family members (41%), friends (23%) or dogs (17%). Only a few respondents (9%) visited on their own.

Comparison of important features in the Hell Fire Club and Massy's Estate

The features which scored highest in both forests were "Smells and atmosphere", "Size of the forest" and "Broadleaf trees" (Figure 1). The "Great view" was considered an important feature in the Hell Fire Club (a coniferous plantation). Also "Parking area" and "Conifer trees" were scored relatively highly compared to those who visited Massy's Estate. In contrast, the visitors of Massy's Estate scored "Stream" relatively high compared to those who visited the Hell Fire Club. There seem to be some confusion among forest visitors as to what was a conifer/broadleaf species. For example, "Broadleaf trees" were rated as a highly important feature of the Hell Fire Club even though there are very few broadleaved trees in the forest, especially along the walking route.

The respondents were asked to choose the five most important well-being benefits of their visit to the forest on the survey day from a list of 16 choices. The benefits that were more frequently mentioned for both forests were "Physical well-being", "Mental relaxation", "Escape and freedom", "Enjoyment and fun" and "Enjoying landscapes", respectively. Benefits such as "Physical well-being", "Enjoyment and

Table 4: *Reasons respondents chose to walk in Massy's Estate instead of the Hell Fire Club. (Figures in parenthesis refer to the number of respondents).*

Category	Answers
Environmental features	Deciduous trees (3) / River (4)
Topography	Easier walk, Hell Fire Club too steep (3) / Easier for children (5)
Familiarity/ Habit	Familiarity (3) / Nearby (1)
Others/comments	Dog friendly (3) / Less people (2) / Well maintained trails (1) / Cleaner (1) / "Not mad on building at Hell Fire Club" (1)

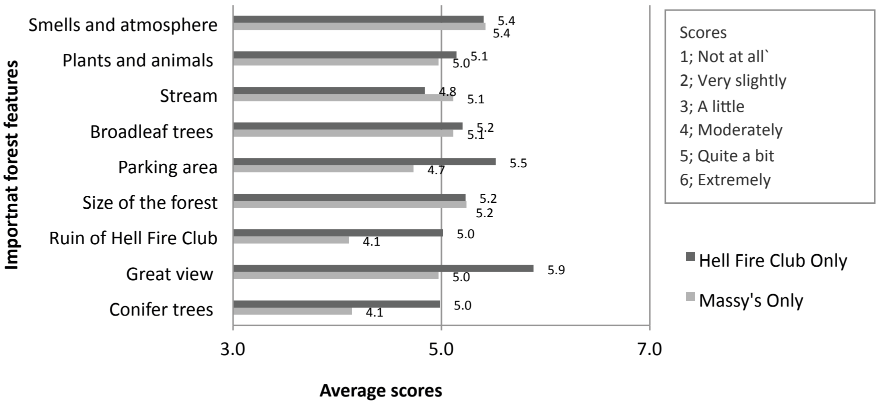

Figure 1: *Ranking of importance of forest features in the Hell Fire Club and Massy's Estate.*

fun" and "Enjoying landscapes" were chosen more frequently by visitors to the Hell Fire Club. Conversely, "Mental relaxation", "Escape and freedom", "Gathering with friends/ family" and "Feeling sense of place" were ranked higher by visitors of Massy's Estate (Figure 2).

Comparison of the mood changes following visits to the Hell Fire Club and Massy's Estate

The visitors to the Hell Fire Club showed an average improvement of 4.9 in their Positive Affect (PA) scale following their walk (Table 5). The visitors to Massy's Estate also showed an improvement in their PA scale after the walk, exhibiting an average increase of 4.0 (Table 5). The changes in PA scales did not differ significantly between forest sites (p = 0.602).

Table 5: *The changes in Positive Affect (PA) scale after walking in the Hell Fire Club compared with Massy's Estate.*

		Positive affect scale			
		n	**Mean**	**SD**[a]	**Paired t-test**
The Hell Fire Club	Before	37	39.2	7.6	t = 3.57,
	After	37	44.1	8.6	p = 0.001
	Average change		+4.9	8.3	
Massy's Estate	Before	45	40.7	7.4	t = 4.02,
	After	45	44.7	8.7	p <0.001
	Average change		+4.0	6.7	

[a] Standard deviation.

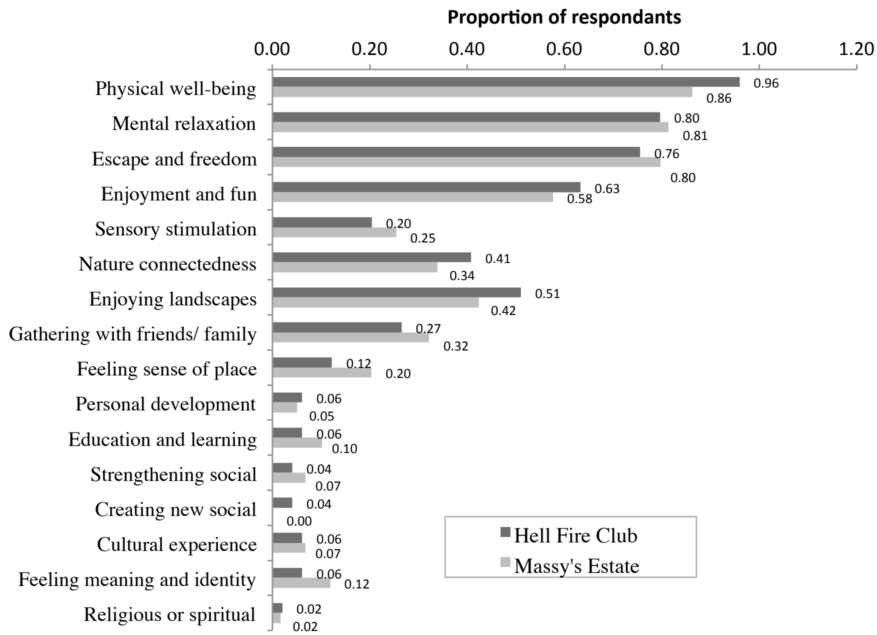

Figure 2: *The well-being benefits provided by the Hell Fire Club and Massy's Estate by proportion of respondents.*

On average, visitors to the Hell Fire Club experienced a statistically significant decrease in their Negative Affect (NA) scale (i.e. -1.8). Visitors to Massy's Estate also experienced a statistically significant decrease in their negative mood (i.e. -1.1) (Table 6). Similar to the results for PA, the changes in the NA scales were independent of the forest site visited (P = 0.398).

The longer-term physical health impacts of spending time in forests

Figure 3 compares the levels of physical activity engaged in by the respondents of this survey with those of a national survey, SLÁN 2007 (Barry et al. 2009). In both surveys the highest proportion of the respondents were categorised as engaging in moderate levels of physical activity (above 45%). However, a higher proportion of the respondents to this survey were categorised as engaging in high levels of physical activity compared to that of the national survey. Chi-square analysis confirmed that the distribution of respondents according to physical activity level differed significantly between both surveys ($\chi^2 = 21.6$, $p < 0.0001$).

Table 6: *The changes in Negative Affect (NA) scale after walking in the Hell Fire Club compared with Massy's Estate.*

		Negative Affect scale			
		n	**Mean**	**SD**[a]	**Paired t-test**
The Hell Fire Club	Before	44	9.9	3.8	t = -3.00,
	After	44	8.1	1.8	p <0.005
	Average change		-1.8	3.9	
Massy's Estate	Before	47	9.2	3.5	t = -2.33,
	After	47	8.1	2.3	p <0.05
	Average change		-1.1	3.3	

[a] Standard deviation.

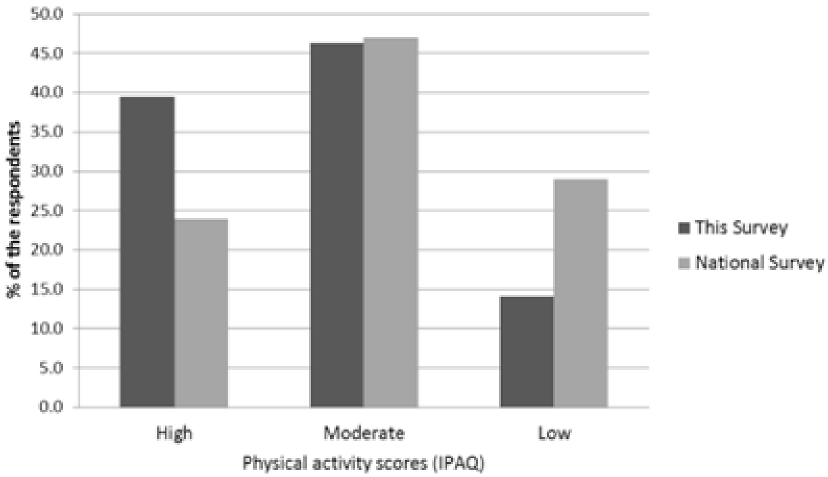

Figure 3: *Comparison of physical activity scores (IPAQ) of the respondents to this survey with those of a national health survey, SLÁN 2007.*

The settings where respondents most commonly exercised were gyms or swimming pools (Figure 4). Only 13% of the respondents' exercise was undertaken in forests.

Regression analysis found that among a number of socio-demographic characteristics, only employment status was shown to be significantly related to the level of physical activity undertaken (Table 7). A Tukey-Kramer post-hoc test indicated that the level of physical activity (the mean MET-minute per week) of non-paid/part-time workers (working less than 8 hrs week^{-1}, unemployed, home maker, other) was significantly higher compared to that of full-time/semi-full-time workers (working full-time 30 hrs + week^{-1}, working 8-29 hrs week^{-1}) ($p < 0.05$). The analysis also showed no significant relationship between the respondent's level of physical activity and frequency of forest visits.

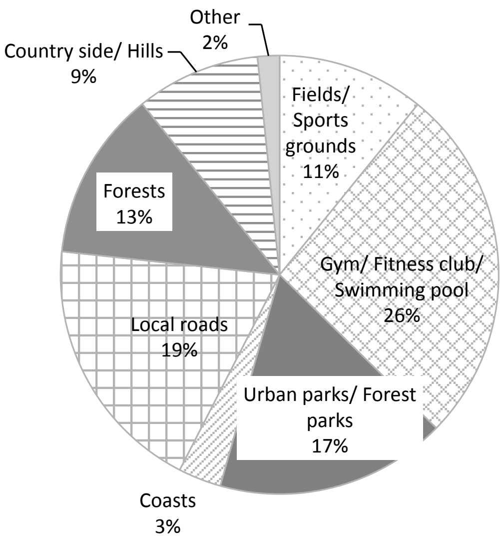

Figure 4: *The proportion of respondent's exercise time spent in various settings.*

Table 7: *Summary of a multiple regression analysis investigating relationships between a series of socio-demographic characteristics and the level of physical activity engaged in by the respondents.*

Source	DF	Type III SS	Mean Square	F Value	Pr > F
Frequency of forest visits	2	3981246	1990623	0.20	0.8173
Age	2	33555062	16777531	1.70	0.1872
Employment	3	84984082	28328027	2.88	0.0399[a]
Education	1	13293672	13293672	1.35	0.2480
Income	1	11164028	11164028	1.13	0.2895
Marital status	1	4931608	4931608	0.50	0.4808
No. of children under 18	1	7746.85	7746.85	0.00	0.9777

[a] $p < 0.05$

The longer-term psychological impacts of forest use

Positive mental health

The overall mean score of the Energy and Vitality Index for the respondents in this survey was 60 (SD = 23), which was significantly lower than the mean score of 68 (SD = 19) reported in the SLÁN 2007 survey (p <0.05). Figure 5 shows that the majority of the forest visitors answered "most of the time" or "sometimes" to the positively worded questions, which was similar to that of SLÁN 2007. It also indicates that the forest visitors in this survey endorsed less of the "very positive" categories (e.g. feeling full of life "all of the time") and less of the "very negative" categories (e.g. feeling tired "never") compared to that of SLÁN 2007.

Psychological distress

In general the responses to the positively worded and negatively worded questions related to psychological distress levels measured by a Mental Health Index-5 (MHI-5) were similar in this and the SLÁN surveys (Figures 6 and 7). However, the overall mean score of MHI-5 for forest visitors was 76 (SD = 23), which was significantly lower than the mean score of 82 (SD = 16) in SLÁN 2007 (p <0.05) suggesting that forest visitors exhibited higher levels of psychological distress than the general population. A score of 52 or less of psychological distress indicates that a respondent has a probable mental health problem (Lavikainen et al. 2006). Five percent of the forest visitors exhibited such low scores. A slightly higher percentage (i.e. 7%) of respondents to the SLÁN 2007 survey scored 52 or less.

Regression analysis found a relationship between employment status and Energy and Vitality Index (p <0.05). A Tukey-Kramer post-hoc test indicated that

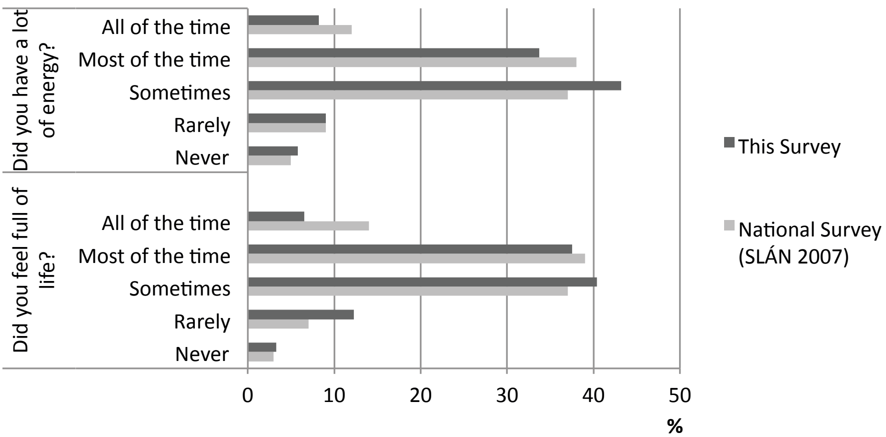

Figure 5: *Comparison of the responses given in this survey and the national survey, SLÁN 2007, to two positively worded items of the Energy and Vitality Index (EVI) by % of respondents.*

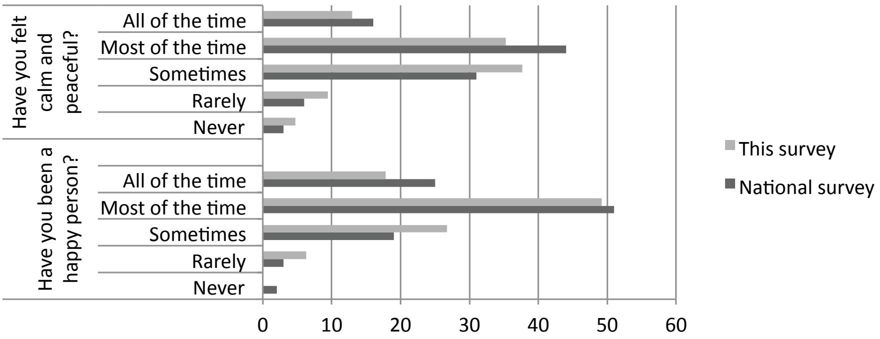

Figure 6: *Comparison of the responses given in this survey and the national survey, SLÁN 2007, to two positively worded items of the Mental Health Index (MHI-5), by % of respondents.*

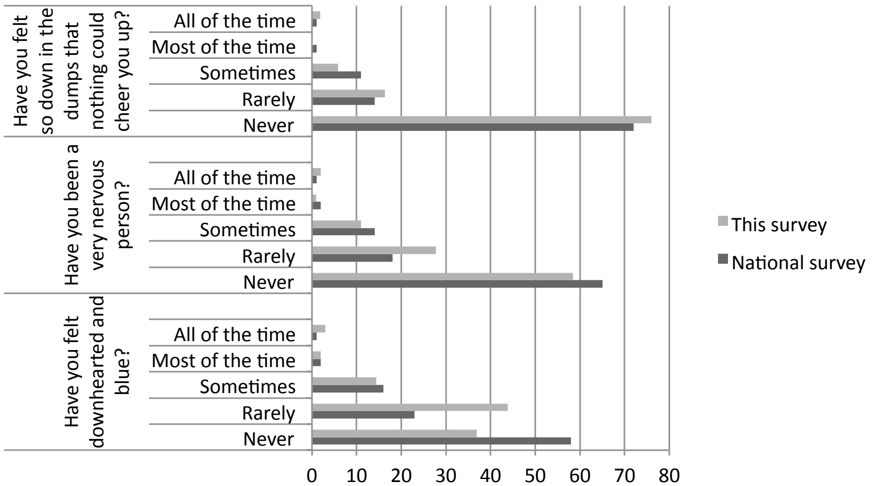

Figure 7: *Comparison of the responses given in this survey and the national survey, SLÁN 2007, to negatively worded items of the Mental Health Index (MHI-5), by % of respondents.*

the mean EVI score of retired individuals was significantly higher than that of full-time/semi-full-time workers ($p < 0.05$). There was also a moderate relationship between the level of physical activity and Energy and Vitality Index ($p = 0.077$). The analysis showed no significant relationship between the respondent's level of Energy and Vitality Index and their frequency of forest visits.

A similar analysis was run to investigate the relationship between the level of psychological distress measured by the Mental Health Index-5 (MHI-5). None of the variables were shown to be significantly related to the MHI-5 scores.

Discussion

The psychological impacts of spending time in forests

A range of psychological health and well-being benefits of spending time in the natural environment have been recognized in previous studies. These include immediate psychological impacts such as improvement of mood, concentration and attention (e.g. Tsunetsugu et al. 2013) as well as longer-term psychological well-being effects such as reduced levels of chronic stress in deprived communities (Ward Thompson et al. 2012).

Based on these previous findings, an attempt was made to identify the psychological and physical well-being benefits experienced by Irish forest users through a questionnaire survey in this study. The results showed that "physical well-being" and "mental relaxation" were the most commonly experienced well-being benefits in this study.

By using Kaplan and Kaplan's Attention Restoration Theory, it is possible to explore the mechanisms through which forest users may have experienced "mental relaxation" with consideration of other well-being benefits chosen by them. First, many of the respondents in this study chose "escape and freedom" as one of the benefits from their forest visits, which supports their experience of a sense of "being away" proposed as one of the restoration processes by Kaplan and Kaplan (1989). Another restoration mechanism recognised in ART is "fascination", which could be reflected in the popular choices of "smells and atmosphere", "plants and animals" and "sensory stimulation" as benefits from the forest visit. Also, the "great view" which was rated highly by the visitors to the Hell Fire Club could be classed as an element of "fascination" (Kaplan and Kaplan 1989). The well-being benefit of "enjoyment and fun" was experienced by many participants. That visitors obtained enjoyment from their visit is further supported by the fact that 71% of the respondents in this study indicated that they visit forests with family, friends or others. It is important to note that others have found that visitation patterns to forests varied according to the day the study was conducted, with families more likely to visit on Sunday (Arnberger and Eder 2007).

Assessments of mood immediately after spending time in forests

In addition to identifying the perceived well-being benefits from forest visits, a more quantitative assessment of the immediate psychological effects of spending time in forests was made using a mood test (PANAS). The results showed that visitors' positive mood improved while their negative mood declined after spending time in a forest. However, whether the same respondents would experience similar changes in mood by walking in a different environment could not be assessed in this study. Nevertheless others have addressed this issue by conducting experiments involving participants walking for a similar length of time in both natural and synthetic environments. Their results have shown that participants experienced greater mood improvements by walking in natural environments compared to urban settings (e.g. Hartig et al. 2003, Berman et al. 2008), laboratories (Plante et al. 2006), or indoor environments (Peacock et al. 2007, Thompson et al. 2011).

It is also important to note that these positive impacts cannot be attributed solely to the exposure to the forest but are likely to develop from a combination of effects arising from increased social interaction and regular exercise. As others have noted (e.g. Berman et al. 2012) these effects are difficult to separate, and could be considered as cumulative.

The effects of species composition of forests on visitors' psychological health/well-being
One of the aims of this study was to investigate whether the species composition of forests influenced the psychological health/well-being gained from spending time in them. Previous studies in Ireland have found that the general public have a preference for broadleaf forests and mixed forests in comparison to conifer-only forests (Clinch 1999, Upton et al. 2012). It was interesting therefore to investigate where such preferences translated into greater well-being benefits for visitors to broadleaf forests compared to coniferous forests. To address this issue surveys of forest visitors were conducted in two forests: a conifer plantation (the Hell Fire Club) and a broadleaf plantation (Massy's Estate). Only those that visited Massy's Estate were directly asked why they chose that site rather than the Hell Fire Club. Only a very small number referred to the species composition. Further, the ranking of the importance of species among the forest features suggested some confusion among forest visitors as to what constituted a conifer/broadleaf species. For example, "broadleaf trees" were rated as a highly important feature of the Hell Fire Club, yet there are very few broadleaf trees in the forest, especially along the walking route.

It should be noted that the two sites had many other distinctive characteristics in addition to species composition. For example, the Hell Fire Club has a steep incline toward the top of hill with an altitude of 383 m, and a ruin on top of the hill, whereas Massy's Estate has relatively flat relief, and has a stream which people can walk along. Hence many people who visited the Hell Fire Club chose the "Great View" as one of the most important features of the site while some people chose to visit Massy's Estate because it is an easier walk, especially for small children. The presence of a river in Massy's Estate was also classed as important for some. Previous studies have identified the psychological effects of spending time near a water body. For example, MacKerron and Mourato (2013) found in their study of more than 20,000 people that, on average, people felt happier outdoors in all-green or natural habitat types than they felt in urban environments; among the green or natural habitats, happiness scores were highest in marine environments and coastal margins. Völker and Kistemann

(2011) also noted that there is a relationship between inland surface waters (referred to as "blue spaces") and human health and well-being. Such findings highlight the complexity of segregating the components of any natural environment that influence well-being. In the case of forests it is even more complex with aspects such as the density of forest, the diameter and height of trees being shown to influence visitors' reactions to a greater extent that species composition (Oishi et al. 2003).

The longer-term physical impacts of spending time in forests

Quantifying the significance of the extent of forest use to forest visitors' longer term physical well-being is an ambitious objective and in reality would require a more in-depth study than was conducted here. Nevertheless, an attempt was made to do so using a simplistic approach which involved a comparison of the self-reported levels of physical activity among forest visitors and those of the general population. This showed that forest visitors in this study engaged in greater levels of physical activity than the general population. In an effort to understand whether these higher levels could in fact be attributed to the time they spent in the forests, the relationship between their physical activity levels and their frequency of forest use was investigated. This analysis did not find that the frequency of forest use was related to their activity levels and similarly no significant relationships were found between a number of socio-demographic characteristics and physical activity levels. Only the employment status of the respondents was shown to be significantly related to the level of physical activities, with non-paid/part-time workers engaging in higher levels of physical activity than full-time/semi-full-time workers. It is also important to note that when correlating frequency of forest use with levels of physical activity that only those who spent some time in a forest were included as only forest visitors were surveyed.

Longer-term psychological impacts

Longer-term psychological impacts of spending time in forests are harder to assess and would require longitudinal studies of visitors. In this study, an attempt was made to assess these impacts by comparing the mental health status of visitors, as measured using a number of indicators, to that of the general population. Somewhat surprisingly this comparison showed that forest visitors had significantly poorer mental health, on average, than the general population (their EVI score measuring positive mental health, and their MHI-5 scores, measuring psychological distress, were lower than that of the general population). However, as highlighted earlier, the study also showed that many people identified mental relaxation and recovery from mental stress as a well-being benefit from visiting forests. These findings suggest that people who are feeling stressed might use forest environments as a means of relief. A deeper exploration of the responses showed that forest visitors expressed less extreme answers to both positive and negative questions included in the EVI suggesting they experienced less extremes in mental health. No statistical correlation was found between the frequency of forest visits and the level of positive mental health and psychological distress.

It is also important to note that the national survey that is being used as a point of comparison here, i.e. the SLÁN 2007 survey, recorded mean scores of EVI that were higher than any recorded in previous Irish studies (e.g. Blake et al. 2000) and higher than those recorded for Ireland in a Eurobarometer 58.2 survey (European Commission 2006). The timing of the study could be relevant as it was conducted during the economic boom in Ireland. The recession and austerity measures that were being experienced in Ireland at the time the forest visitor survey was conducted might also account for the lower than expected relative EVI and MHI-5 values that were recorded among the forest visitors. As further support to this, a significant correlation between employment status and the level of mental health was noted in this study. Also, it should be noted that this survey was conducted in winter time (November and January). This might have influenced the mental health of respondents as other studies have shown that people generally feel happier in the summer time when the average temperature is greater (MacKerron and Mourato 2013).

Conclusions

This study attempted to investigate the psychological and physical impacts of spending time in forests in Ireland by conducting a questionnaire study targeted at visitors to Irish forests. Unfortunately, the resources which were available limited the data collection to a once-off survey of a sample of forest visitors. Nevertheless the results suggested that forest visitors experience psychological well-being benefits such as "mental relaxation" and "enjoyment and fun". They also experienced significant improvements in mood immediately after spending time in a forest. The role of the species composition of the forest visited appeared to be less important than other features such as the topography and the view.

The mental health of forest visitors was shown to be poorer, on average, than the general population, although walking in the forests was shown to improve their mood. This finding highlights that where long-term links between health and use of environments (such as forests) are studied, the direction of causation may run either way. No causative link can be attributed with certainty between the number of forest visits and the health of the visitors in this study.

Overall the findings of the study suggest that there are benefits to be gained by improving accessibility to forests in Ireland provided the sites are well managed. The sites are likely to attract more people if there are several attractions such as scenic views and water bodies, in addition to facilities such as car parks.

Further research on the longer-term health benefits of forests should be conducted and should involve large-scale longitudinal studies of visitors and non-visitors to a range of forests. Surveys of forest visitors that would be undertaken as part of these studies should take place over a range of days and months to account for temporal trends in visitation patterns to forests.

Acknowledgements
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References

Arnberger, A. and Eder, R. 2007. Monitoring recreational activities in urban forests using long-term video observation. *Forestry* 80: 1–15.

Barry, M.M., Van Lente, E., Molcho. M., Morgan, K., McGee, H., Conroy, R.M., Watson, D., Shelley, E. and Perry, I. 2009. *SLAN 2007: Survey of Lifestyle, Attitudes and Nutrition in Ireland*. Mental health and social well-being report, Department of Health and Children. The Stationery Office, Dublin.

Berman, M.G., Jonides, J. and Kaplan, S. 2008. The cognitive benefits of interacting with nature. *Psychological Science* 19: 1207–1212.

Berman, M.G., Kross, E., Krpan, K.M., Askren, M.K., Burson, A., Deldin, P.J., Kaplan, S., Sherdell, L., Gotlib, I.H. and Jonides, J. 2012. Interacting with nature improves cognition and affect for individuals with depression. *Journal of Affective Disorders* 140: 300–305.

Blake, C., Codd, M.B. and O'Meara, Y.M. 2000. The short form 36 (SF-36) health survey: normative data for the Irish population. *Irish Journal of Medical Science* 169: 195–200.

Bowler, D.E., Buyung-Ali, L.M., Knight, T.M. and Pullin, S. 2010. A systematic review of evidence for the added benefits of health and exposure to natural environments. *BMC Public Health* 10: 456–466.

Clinch, J.P. 1999. *Economics of Irish Forestry: Evaluating the Returns to Economy and Society*. COFORD, Dublin.

European Commission. 2006. *Mental Well-being. Special Eurobarometer 248/Wave 64.4 – TNS Opinion and Social*. European Commission, Brussels. Available at: http://ec.europa.eu/public_opinion/archives/ebs/ebs_248_en.pdf [Retrieved September 2013].

Forestry Commission Scotland. 2015. *A Strategic Framework, Wood in and Around Towns* (WIAT) Programme 2015–2020: Phase 4 sustaining delivery. Available at: http://scotland.forestry.gov.uk/images/corporate/pdf/wiat-framework.pdf [Retrieved July 2016].

Forest Therapy Society. 2013. Available at: http://www.fo-society.jp/quarter/chubu/agematsu.html [Accessed, in Japanese, September 2016].

Hartig, T., Evans, G.W., Jamner, L.D., Davis, D.S. and Gärling, T. 2003. Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology* 23(2): 109–123.

Hartig, T., Mitchell, R., de Vries, S. and Frumkin, H. 2014. Nature and health. *Annual Review of Public Health* 35: 207–228.

IBM Corp. 2011. *IBM SPSS Statistics for Windows*, Version 20.0. IBM Corp., Armonk, New York.

IPAQ (International Physical Activity Questionnaire) 2005. *Guidelines for Data Processing and Analysis of the International Physical Activity Questionnaire (IPAQ): Short and Long Forms*. Retrieved from http://www.ipaq.ki.se/scoring.pdf [Accessed October 2013].

Iwata, Y., Ní Dhubháin, Á., Brophy, J., Roddy, D., Burke, C. and Murphy, B. 2016. Benefits of group walking in forests for people with significant mental ill-health. *Ecopsychology* 8: 16–26.

Kaplan, R. 1983. The role of nature in the urban context. In Altman, I. and Wohlwill, J.F. (Eds.), *Behavior and the Natural Environment*, Plenum Press, New York, pp. 127–162.

Kaplan, R. and Kaplan, S. 1989. *The Experience Of Nature: A Psychological Perspective*. Cambridge University Press, Cambridge,

Lavikainen, J., Fryers, T. and Lehtinen, V. eds. 2006. Improving mental health information in Europe. Proposal of the MINDFUL project. Helsinki: STAKES. Available at: www.stakes.fi/pdf/mentalhealth/Mindful_verkkoversio.pdf [Retrieved June 2013].

Li, Q., Morimoto, K., Kobayashi, M., Inagaki, H., Katsumata, M. and Hirata, Y. 2008. Visiting a forest, but not a city, increases human natural killer activity and expression of anti-cancer proteins. *International Journal of Immunopathology Pharmacology* 21: 117–28.

MacKerron, G. and Mourato, S. 2013. Happiness is greater in natural environments. *Global Environmental Change* 23: 992–1000.

Magner, D. 2011. Stopping by Woods. *A Guide to the Forests and Woodlands for Ireland*. The Lilliput Press, Dublin

Maretzki, T.W. 1987. The Kur in West Germany as an interface between naturopathic and allopathic ideologies. *Social Science and Medicine* 24: 1061–1068.

O'Brien, L. and Morris, J. 2013. Well-being for all? The social distribution of benefits gained from woodlands and forests in Britain. *Local Environment: The International Journal of Justice and Sustainability* 19(4): 356–383

Oishi, Y., Kanehama, S., Hiyane, A. and Taguchi, H. 2003. Comparison of forest image and mood: Psychological examination in a forest environment using profile of mood states and semantic differential method. *Japan Forestry Society* 85 (1): 70–77. [In Japanese.]

Peacock, J., Hine, R. and Pretty, J. 2007. The mental health benefits of green exercise activities and green care. Report for MIND 2007. Retrieved from: www.psykinfo.regionsyddanmark.dk/dwn109161.pdf [Accessed August 2013].

Plante, T.G., Cage, C., Clements, S. and Stover, A. 2006. Psychological benefits of exercise paired with virtual reality: outdoor exercise energizes whereas indoor virtual exercise relaxes. *International Journal of Stress Management* 13: 108–117.

Richardson, E.A., Pearce, J., Mitchell, R. and Kingham, S. 2013. Role of physical activity in the relationship between urban green space and health. *Public Health* 127: 318–24.

SAS Institute Inc. 2011. *Base SAS® 9.3 Procedures Guide*. Cary. NC: SAS Institute Inc.

Thompson, C.J., Boddy, K., Stein, K., Whear, R., Barton, J. and Depledge, M.H. 2011. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. *Environmental Science and Technology* 45: 1761–1772.

Tsunetsugu, Y., Lee, J., Park, B.J., Tyrväinen, L., Kagawa, T. and Miyazaki, Y. 2013. Physiological and psychological effects of viewing urban forest landscapes assessed by multiple measurements. *Landscape and Urban Planning* 113: 90–93.

Ulrich, R.S. 1983. Aesthetic and affective response to natural environment. In Altman, I. and Wohlwill, J.F. (Eds.), *Behavior and the Natural Environment,* Plenum Press, New York: pp. 85–125.

Ulrich, R.S., Simons, R.T., Losito, B.D., Fiorito, E., Miles, M.A. and Zelson, M. 1991. Stress recovery during exposure to natural and urban environments. *Journal of Environmental Psychology* 11: 201–230.

Upton, V., Ní Dhubháin, Á. and Bullock, C. 2012. Preferences and values for afforestation: the effects of location and respondent understanding on forest attributes in a labelled choice experiment. *Forest Policy and Economics* 23: 17–27.

Völker, S. and Kistemann, T. 2011. The impact of blue space on human health and well-being – Salutogenetic health effects of inland surface waters: a review. *International Journal of Hygiene and Environmental Health* 214: 449–460.

Ward Thompson, C., Roe, J., Aspinall, P., Mitchell, R., Clow, A. and Miller, D. 2012. More green space is linked to less stress in deprived communities: evidence from salivary cortisol patterns. *Landscape and Urban Planning* 105: 221–29.

Ware, J.E., Snow, K.K., Kosinski, M. and Gandek, B. 1993. SF-36 *Health Survey Manual and Interpretation Guide*. Boston, MA, New England Medical Center, The Health Institute.

Watson, D., Clark, L.A. and Tellegan, A. 1988. Development and validation of brief measures of positive and negative affect: The PANAS scales. *Journal of Personality and Social Psychology* 54: 1063–1070.

Forest Perspectives

"Finely furnished with trees" The ceremonial planting of the grounds of *Áras an Uachtaráin*

Mary Forrest[a*]

Introduction

The genesis of tree collections in Ireland is varied. The National Botanic Gardens, Glasnevin, was founded in 1795 by the (Royal) Dublin Society with the ongoing purpose to develop plant collections, including trees; foster botanical studies and promote knowledge of plants among the general public. In the 19th century and early 20th century landowners such as the Viscount Powerscourt at Powerscourt, Enniskerry, Co. Wicklow and the Marquess of Headfort, Kells, Co. Meath had a keen interest in the tree species then being introduced into cultivation from temperate regions of the world. They planted notable collections of coniferous and broadleaved trees, much of which remain extant. In 1905 State development of forestry provided the impetus for planting some 100 coniferous and broadleaved species in experimental blocks at Avondale, Co. Wicklow. Tree collections were also developed to remember a person or particular commemorative event. A notable illustration of the former being the John F. Kennedy Memorial Park and Arboretum, New Ross, Co. Wexford, an arboretum dating from 1968 comprising some 4,500 trees and shrubs. An example of the latter, the Millennium Arboretum, St. Anne's Park, Raheny, Dublin was planted in 1988 with 1,000 different trees purchased by public subscription, to mark the foundation of Dublin in 888 A.D. Trees are also planted for ceremonial purposes and a unique collection of such trees is cultivated in the grounds of *Áras an Uachtaráin* in the Phoenix Park, Dublin.

Keywords: *Tree Collections, Phoenix Park, Dublin*

The grounds of *Áras an Uachtaráin*

Áras an Uachtaráin is one of three demesne landscapes in the 707 ha (1,752 acre) Phoenix Park. Originally the residence of the Park Ranger, Robert Clements, since 1782 it has been the official residence of the Lords Lieutenant, the Governors General

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(1922 – 1937) and since 1938 the Presidents of Ireland (Anon. 2013). The grounds extend to 56 ha (139 acres).

An early map c. 1775 by Asser (McCullen 2009*)* shows a wooded landscape to the left of the house, walled gardens to the right, lawn to the south and fields to the north. In the early 19th century, planting of this wooded landscape and the pleasure grounds closer to the residence continued. In 1855 the pleasure grounds were refurbished and planted with conifers supplied by Oakdale Nurseries, Liverpool and Ninian Niven, nurseryman, Drumcondra, from a list compiled by Mr. Wilkie, the Park bailiff (Mc Cullen 2009). This work caught the attention of horticultural writers of the period. William Robinson who was to give his name to a style of gardening, visited the grounds in 1865. He wrote, “To the north of the flower garden is the “wild garden”, half pleasure ground, half wilderness, and in which when Lord St. Germans left in 1855 each of his family planted a tree” (Robinson 1865). Visiting Irish gardens in 1870, a correspondent wrote, “The private policies and gardens are of considerable extent, finely furnished with trees, tastefully laid out, and pretty well maintained” (B 1870).

These writers would have seen a representative collection of conifers which formed a “Pinetum”, an arboretum confined to conifers (Figure 1). Among the trees in this area today are mature specimens of Italian cypress (*Cupressus sempervirens*[1]) from the Mediterranean region; yew trees (*Taxus baccata*) from Europe, including several Irish yew (*Taxus baccata* “Fastigiata”); two specimens of Oriental spruce (*Picea orientalis*) from the Caucasus and Turkey; incense cedar (*Calocedrus decurrens*), Lawson cypress (*Chamaecyparis lawsoniana*), several western red cedar (*Thuja plicata*) all from western North America; morinda spruce (*Picea smithiana*), from the region Afghanistan to Nepal; and several deodar cedars (*Cedrus deodara*), native to the Himalayas. At this time shrubs such as cherry laurel (*Prunus laurocerasus*) and Portugal laurel (*P. lusitanica*) were planted to form shrubberies and many remain, together with a weeping ash (*Fraxinus excelsior* “Pendula”), a popular specimen tree of the Victorian and Edwardian period.

Ceremonial trees

From the mid-19th century ceremonial tree planting has taken place in the grounds (Figure 2). Metal plaques in various sizes and styles with lettering in English or Irish or other languages, give the name of the tree and record the name of the person who planted it and the date of planting. From September 1853, when Queen Victoria planted the first of three trees in the grounds, to 1922, trees were planted by members of the British Royal family, Lords Lieutenant of Ireland and the Prime Minister of Canada. From 1939 to the present, ceremonial trees have been planted by Presidents of Ireland and visiting Heads of State from many countries. A list of ceremonial trees planted from 1853 to date is given in Table 1.

[1] The full scientific notation is included with all species presented in Table 1.

Figure 1: *View of the Pinetum. Kay Hartigan, Diarmuid McAree, Kevin Hutchinson and Michael O'Brien of the Tree Council of Ireland visited Áras an Uachtaráin in June 2015. The photographs that appear in this article were taken by Mary Forrest and are used with the permission of the Press Officer of Áras an Uachtaráin.*

The first tree on what became known as the Queen's Walk, which is located to the left of the front lawn of the residence, is an oak. A large metal sign reads "*Quercus robur pedunculata* Irish Oak Planted by Her Most Gracious Majesty Queen Victoria September 1853". The Walk is lined with now mature trees, deciduous horse chestnuts (*Aesculus hippocastanum*), common and copper beech (*Fagus sylvatica*, *F. sylvatica* f. *purpurea*) and pedunculate oak and evergreen Lawson cypress. While these trees are commonly seen in avenues or as parkland trees, Canadian maple (*Acer rubrum*), is

Figure 2: *Ceremonial trees line the entrance drive to Áras an Uachtaráin.*

unusual. Two specimens were planted by the Prime Minister of Canada Sir Wilfrid and his wife, Lady Laurier in July 1907. He came to Dublin to visit the Irish International Exhibition at which there was a Canadian pavilion (Anon 1907). Not all ceremonial trees have survived. Two Cornish elm trees (*Ulmus angustifolia* var. *cornubiensis*) planted by the last two Lords Lieutenant of Ireland, succumbed to Dutch Elm Disease.

To the south of the residence a formal parterre with lawns and formal bedding schemes and a row of Irish yew, defining the outline of the area, is known as the Front Lawn. One tree, a giant redwood (*Sequioadendron giganteum*), stands out. The commemorative plaque reads, "Wellingtonia gigantea planted by Her Most Gracious Majesty Queen Victoria August 1861". Two specimens were noted by William Robinson (1865) when he visited the Phoenix Park. The tree planted by Prince Albert, Prince Consort, did not survive. The only other ceremonial tree planted on the Front Lawn was a pedunculate oak was planted by Pope John Paul II in September 1979. By 2015, it had developed to display the typical domed shape of the species.

Within close view of the giant redwood planted by Queen Victoria stand two further trees of the same species planted by President de Valera and President John F. Kennedy, President of the United States of America on 27th June 1963. While both trees demonstrate the conical habit of the species, they are smaller than might be expected after 50 years growth. One tree which forked low on the trunk is beginning to develop some strong branches.

Trees planted by Presidents of Ireland

Each President of Ireland has planted one or more trees in the grounds. To mark his first year in office, President Douglas Hyde planted a Cornish elm, on the North Lawn. Two dates are given for the ceremony; 22nd March 1939 and 25th June 1939. Given that photographs of the ceremony show a bare-stemmed tree with the President and his party wearing overcoats and hats, the earlier date is likely to be correct (Mc Cullen 1993 and www.president.ie). The tree succumbed to Dutch elm disease and was felled in 1985. A story told that the original tree was planted on a flat stone proved to be true when the remains were cleared. Happily, propagation by tip cuttings had previously been undertaken by Teagasc and several young trees were planted in the Walled Garden and a specimen was planted by President McAleese on the site of the original tree (Figure 3).

On 9th November 1948, President Sean T. O'Ceallaigh and his wife Phyllis Ní Riain each planted Irish pedunculate oak trees on The Queens's Walk. Plaques, written in Irish, record the planting on February 2nd 1962 of native Irish trees -oak by President de Valera and ash (*Fraxinus excelsior*) and rowan (*Sorbus aucuparia*) by Sinéad Bean de Valera. Eleven years later on 11th May 1973, President de Valera and the Head of the Jewish Community in Ireland planted three Aleppo pine specimens (*Pinus halapensis*). At a memorial service in memory of the President in 1975, the Chief Rabbi recalled this event saying that young trees from the Eamon de Valera forest, which had been established by the Irish Jewish Community in Israel, were planted by the late President (Cooney 1975).

Figure 3: *An elm tree planted by President McAleese, a cutting of the tree planted by President Hyde in 1939.*

Trees were planted in the area between the West Wing and the Arboretum in memory of two presidents. On 16th December 1975 Rita Childers, widow of President Erskine Childers and his daughter, Nessa, planted a magnolia (*Magnolia grandiflora*) and a strawberry tree (*Arbutus unedo*), respectively. In April 1978, two whitebeam trees (*S. aria*) and a weeping birch (*Betula pendula* "Youngii") were planted in memory of Cearbhaill O'Dálaigh, President 1974 – 1976, by Máirín Bean Uí Dhálaigh and Aidan Carl Mathews, godson of the President.

Two large-growing ornamental trees were planted by President Patrick Hillery and Mrs Maeve Hillery on 19th May 1978. They were respectively, a copper beech (*F. sylvatica* "Purpurea") and a blue atlas cedar (*Cedrus atlantica* "Glauca"). On 17th March 1984, President Hillery planted an ash to mark "Trees for Ireland" National Arbor Day (Fitzpatrick n.d.). Four years later, the President and Mrs Hillery each planted a pedunculate oak to mark the Millennium celebrations of the City of Dublin.

On 5th November 1991 President Mary Robinson planted a sapling oak to mark the launch of Acorn month. The aim of the *Grow Your Own Oak Tree* environmental project was to plant 250,000 oak trees. This was a joint project between ECO, the environmental youth organisation and Jet Oil who were supplying acorns from their petrol stations (Anon. 1991). To mark the launch of the National Tree Week programme for 1991, President Robinson planted a beech in a paddock to the north side of the Áras. On 23rd April 1996, President Robinson and her husband, Nicholas Robinson, each planted a pedunculate oak in the Arboretum.

The Family Tree Scheme was initiated by the Tree Council of Ireland in 1988 and continues to the present time. In January 2000 President Mary McAleese and her family planted seven bay laurel trees (*Laurus nobilis*). Before leaving office in November 2011, President McAleese planted an upright English oak (*Quercus robur* "Fastigiata") close to the bell by the entrance to the Racquet Hall. President McAleese also planted a Cornish elm to replace a tree planted by President Hyde (see earlier).

To mark ESB National Tree Week on March 3rd 2015, President Michael D. Higgins planted a blue atlas cedar (*C. atlantica* "Glauca") and Mrs Sabina Higgins planted a Cedar of Lebanon (*C. libani*) on either side of the main avenue leading to their official residence (Anon. 2105). Their selection augmented the existing conifer collection in the grounds.

As part of the "Ireland 1916" centenary commemorations programme, President Higgins hosted a "Children seen and heard 1916 – 2016" event on 15th June 2016. In the presence of 300 children, the President planted a pedunculate oak and buried a time capsule. While school children have been attending ceremonial tree planting by visiting heads of state for many years, this was the first ceremonial tree planting organized specifically for young people.

Ceremonial trees planted by visiting Heads of State

Apart from an oak planted by President Charles de Gaulle in the Queen's Walk in 1969, all ceremonial trees planted by visiting Heads of State were planted to the west of *Áras an Uachtaráin*. These trees are planted either side of a broad serpentine road which leads from the entrance gates to the residence.

In the 1980s and 1990s visiting heads of state have planted trees native to their own countries. In 1985 Crown Prince Akihito planted a Kadsura tree (*Cercidiphyllum japonicum*) Twenty years later the then Emperor and Empress of Japan examined the now mature tree in the company of President and Dr. McAleese (Donaghy and Byrne 2005). The President of Austria planted a lime (*Tilia cordata*) while the King of Sweden planted a Swedish whitebeam (*Sorbus intermedia*). The *Magnolia grandiflora* planted by President Ronald Reagan, President of the United States, was "doubly American" as it were, being native to the southern and eastern United States and propagated from a cutting of a tree cultivated in the gardens of the White House. In 1995 a later President of the United States, President Bill Clinton planted an 8-year-old oak on the West Avenue. From the late 1990s, visiting Heads of State have planted *Q. robur* trees.

The Peace Bell stands between the west corner of *Áras an Uachtaráin* and the Racquet Court. Three specimens of *Q. robur* "Fastigiata" an upright form of oak were planted in front of the Bell by Queen Elizabeth II and President Barack Obama on the occasion of their visits to Ireland on 17th and 23rd May 2011 respectively, as well as by President McAleese on 4th November 2011.

Present day Tree Management

A carpet of mulch has been spread under and between the ceremonial trees on the Queen's Walk to prevent root damage as the soils are prone to compaction (Figure 4). Newly planted trees are supported with a short stake and protected by spiral rabbit guards. Large metal tree guards, a distinctive feature of the Phoenix Park in general, protect trees from the cattle which graze the paddocks. To encourage growth and prevent compaction, a circle of ground beneath the tree is maintained weed free and mulched with bark.

On the formal parterres closely mown grass accentuates the extent of the lawns. The policy of improving biodiversity within the Phoenix Park also includes *Áras an Uachtaráin*. Extensive areas of the parkland and grounds of the *Áras* are actively managed as wild-flower meadows, with annual mowing in early autumn, so as to prevent any damage to ground nesting birds. The tree collection within the *Áras* is regularly surveyed, inspected and managed in accordance with best practice by the Office of Public Works professional staff. The trees in general are very healthy with a number now reaching maturity. However, some of the horse chestnut trees are showing early

Figure 4: *The Queen's Walk, Áras an Uachtaráin.*

signs of bleeding canker. The tree collection shows the merit of initial wide spacing at the time of planting so that trees may attain the full dimensions typical of their species.

The practice of visiting Heads of State planting *Q. robur* has become policy. As well as being a native species, the tree is long-lived and in time will be in scale with the residence and the surrounding perimeter of parkland trees. Together with *Fraxinus*, *Betula*, *Arbutus* and *Sorbus* spp., they have become a fitting representative collection of trees native to Ireland. With the exception of the 1950s, some ceremonial planting has taken place in each decade from the 1850s to the present. Most of the trees planted are of long-lived nature. With the sequential development and senescence of these trees, a continuing generational evolution in tree cover will be maintained in the grounds.

Since the date of planting of each tree is known, the growth rate of trees can be recorded. Some specimens (Table 2) are included in the Tree Register of Ireland, a register of 11,000 trees maintained by the Tree Council of Ireland and the Irish Tree Society (Tree Council website). With the exception of the National Botanic Gardens in Glasnevin, it is doubtful whether continuous recorded planting over a 160-year period has occurred elsewhere in Ireland. Details of similar collections of ceremonial trees in other countries, if they exist, have not come to light. The ceremonial trees are also a reminder of the successive residents of *Áras an Uachtaráin*, the many Heads of State who have visited them and by extension the Irish people.

The grounds of *Áras an Uachtaráin* were described in the 1870s as "finely furnished with trees" and remain so a century and a half later.

Table 1: *A complete list of ceremonial trees planted in Áras an Uachtaráin (adapted from Mc Cullen (1993) and augmented by Margaret Gormley (Chief Park Superintendent, 28th October 2015)).*

Date	Head of State /Country	Name of Tree	Common Name	Location
1853	Queen Victoria	*Quercus robur* L.	Pedunculate oak	The Queen's Walk
1861	Queen Victoria	*Sequoiadendron giganteum* (Lindl.) Buchholz	Giant sequoia, Wellingtonia Redwood	Front Lawn
1869, 27th April	Prince Arthur Patrick	*Sequoiadendron giganteum*		The Queen's Walk
1897, 28th August	The Duke of York	*Chamaecyparis lawsoniana* (Murr.) Parlatore	Lawson cypress	The Queen's Walk
1897, 28th August	The Duchess of York	*Chamaecyparis lawsoniana*		The Queen's Walk
1900, 24th April	Queen Victoria	*Quercus robur*	Oak	The Queen's Walk
1900, 24th April	Princess Henry of Battenburg	*Fagus sylvatica* f. *purpurea* (Ait.) Schneid.	Copper beech	The Queen's Walk
1900, 24th April	Princes Alexander Leopold and Maurice of Battenburg	*Fagus sylvatica* L.	Beech	The Queen's Walk
1900, 25th April	Princess Victoria Eugenie of Battenburg	*Fagus sylvatica*		The Queen's Walk
1900, 26th April	Princess Christian of Schleswig-Holstien	*Fagus sylvatica* f. *purpurea*		The Queen's Walk
1904, 21st April	Princess Margaret of Connaught	*Fagus sylvatica* f. *purpurea*		The Queen's Walk
1904, 21st April	Princess Patricia of Connaught	*Fagus sylvatica*		The Queen's Walk
1904, 21st April	The Duke of Connaught	*Quercus robur*		The Queen's Walk
1904, 21st April	The Duchess of Connaught	*Fagus sylvatica*		The Queen's Walk
1904, 30th April	Princess Victoria	*Aesculus hippocastanum* L.	Horse chestnut	The Queen's Walk
1904, 30th April	King Edward VII	*Quercus robur*		The Queen's Walk
1904, 30th April	Queen Alexandra	*Fagus sylvatica*		The Queen's Walk

1904, May	Prince Arthur of Connaught	*Fagus sylvatica* f. *purpurea*		The Queen's Walk
1907, 8th July	Sir Wilfrid Laurier, Prime Minister of Canada	*Acer rubrum* L.	Canadian Maple	The Queen's Walk
1907, 8th July	Lady Laurier	*Acer rubrum*		The Queen's Walk
1907, 19th December	Lord Aberdeen, Lord Lieutenant of Ireland	*Acer rubrum* [replanted]		The Queen's Walk
1907, 19th December	Lady Aberdeen, wife of Lord Lieutenant of Ireland	*Acer rubrum*		The Queen's Walk
1908, 20th April	Marchioness of Londonderry	*Fagus sylvatica*		The Queen's Walk
1911, 9th July	Prince of Wales	*Fagus sylvatica*		The Queen's Walk
1911, 9th July	Princess Mary	*Fagus sylvatica*		The Queen's Walk
1921, 23rd February	Viscount French of Ypres, Lord Lieutenant of Ireland	*Ulmus angustifolia* var. *cornubiensis* (Weston) Rehd.	Cornish Elm [died]	The Queen's Walk
1922, 21st November	Viscount Fitzalen of Derwent, Lord Lieutenant of Ireland	*Ulmus angustifolia* var. *cornubiensis* [died]		The Queen's Walk
1922, 21st November	Viscountess Fitzalen of Derwent	*Fagus sylvatica* f. *purpurea*		The Queen's Walk
1946, 1st October	Presented by Lord Mountbatten of Burma to President O'Kelly	*Fagus sylvatica* f. *purpurea*		The Queen's Walk
1948, 22nd July	An Taoiseach, John A. Costelloe; J. Blowick, Minister for Lands; Councillor J. Breen, Lord Mayor of Dublin; Sean Moylan T.D. Monsignor Michael J. Curran PP, Bray; Sir Shane Leslie	*Cedrus atlantica* (Endl.) Carr.	Atlas Cedar	Adjacent to Lime Walk Six of 12 trees donated by "The Men of the Trees' on the occasion of their visit.
1948, 9th November	Maximillian Claudia Habsburg Lothringen, Prince of Firenze	*Quercus*		The Queen's Walk
1948, 9th November	Claudia Habsburg Lothringen, Princess of Firenze	*Quercus*		The Queen's Walk

Table 1: *Continued.*

Date	Head of State /Country	Name of Tree	Common Name	Location
1948, 9th November	Gertrud Habsburg Lothringen, Princess of Firenze	*Quercus*		The Queen's Walk
1962, 2nd February	President de Valera	*Quercus robur*		Off West Wing to Arboretum
1962, 2nd February	Bean de Valera	*Fraxinus excelsior* L. and *Sorbus aucuparia* L.	Ash and rowan	Off West Wing to Arboretum
1963, 27th June	President J.F. Kennedy, USA	*Sequoiadendron giganteum*		Off West Wing to Arboretum
1963, 27th June	President de Valera	*Sequoiadendron giganteum*		Off West Wing to Arboretum
1968, 17th May	King Baudouin of Belgium	*Quercus robur*		The Queen's Walk
1968, 17th May	Queen Fabiola of Belgium	*Fagus sylvatica*		The Queen's Walk
1969, 18th June	President de Gaulle France	*Quercus robur*		The Queen's Walk
1969, 18th June	Madame de Gaulle France	*Fraxinus excelsior*		The Queen's Walk
1973, 11th May	President de Valera and Head of Jewish Community in Ireland	*Pinus halapensis* Mill.	Aleppo pine	
1975, 16th December	Mrs. Rita Childers, wife of President Childers	*Magnolia grandiflora* L.	Evergreen magnolia	Off West Wing to Arboretum
1975, 16th December	Nessa Childers, daughter of President Childers	*Arbutus unedo* L.	Strawberry tree	Off West Wing to Arboretum
1976, 6th August	Walter Scheel, West Germany	*Tilia platyphyllos* Scop. rubra	Lime	Off West Wing to Arboretum
1976, 6th August	Frau Mildred Scheel	*Tilia platyphyllos* rubra		Off West Wing to Arboretum
1978, 14th April	Máirín Bean Uí Dhálaigh	*Sorbus aria* L.	Crantz whitebeam	Off West Wing to Arboretum
1978, 14th April	Aidan Carl Mathews, godson of President O'Dálaigh	*Betula pendula* Roth "Youngii"	Birch	Off West Wing to Arboretum
1978, 24th April	Prince Henrik of Denmark	*Fagus sylvatica*		The Queen's Walk
1978, 24th April	Queen Margrethe of Denmark	*Quercus robur*		The Queen's Walk
1978, 19th May	President Patrick Hillery	*Fagus sylvatica* f. *purpurea*		Arboretum
1978, 19th May	Mrs. Maeve Hillery	*Cedrus atlantica* "Glauca"	Blue Cedar	Arboretum

1979, 9th September	J.K. Nyerere, President of Tanzania	*Fagus sylvatica* "Rohanii"		The Queen's Walk
1979, 29th September	Pope John Paul II, Vatican	*Quercus robur*		Front Lawn
1980, 29th April	Karl Carstens, President of Germany	*Tilia × euchlora* L.	Common lime	The Queen's Walk
1982, 3rd May	Shri Neelam Sanjiva Reddy, President of India	*Quercus robur*		Arboretum
1982, 2nd June	Grand Duke of Luxembourg	*Quercus petraea* (Mattuschka) Lieblein	Sessile oak	The Queen's Walk
1984, 17th March	President Patrick Hillery	*Fraxinus excelsior*		Arboretum
1984, 3rd June	Mr. Ronald Reagan, President USA	*Magnolia grandiflora*	Evergreen magnolia	From a cutting of a tree in the gardens of the White House, Washington
1985, 4th April	Prince Akihito and Princess Michiko, Crown Prince and Princess of Japan	*Cercidiphyllum japonicum* Sieb. and Zucc.	Kadsura tree	Arboretum
1985, June	Chaim Hertzog, President of Israel	*Laurus nobilis* L.	Bay laurel	Planted by OPW staff off West Wing to Arboretum
1986, 9th June	Francesco Cossiga, President of Italy	*Arbutus unedo*	Strawberry tree	Arboretum
1986, 29th June	King Juan Carlos of Spain	*Castanea sativa* Mill.	Spanish chestnut	Arboretum
1988, 28th February	Francois Mitterand, President of France	*Quercus robur*		Arboretum
1988, 29th April	President Patrick Hillery	*Quercus robur*		Arboretum
1988, 29th April	Mrs. Maeve Hillery	*Qurcus robur*		Arboretum
1989, 7th May	50th Anniversary of the Irish Red Cross	*Quercus robur*		Arboretum
1990, 30th October	Queen Beatrix of The Netherlands	*Tilia cordata* Mill.	Lime	Arboretum

Table 1: *Continued.*

Date	Head of State /Country	Name of Tree	Common Name	Location
1991, 11th February	President Mary Robinson	*Fagus sylvatica*		Paddock on north side of Áras an Uachtaráin
1991, 3rd October	Vigdis Finnbogadottir, President of Iceland	*Betula pendula* Roth.	Silver Birch	Arboretum
1991, 5th November	President Mary Robinson	*Quercus robur*		Paddock on north side of Áras an Uachtaráin
1992, 7th April	King Carl Gustav XVI of Sweden	*Sorbus intermedia* (Ehrh.) Pers.	Swedish whitebeam	Arboretum
1992, 20th July	Dr. Richard von Weizsäcker, Federal Republic of Germany	*Tilia*	Lime	Arboretum
1993, 1st June	President Soares, President of Portugal	*Pinus pinea* L.	Stone pine	Hyde Room
1994, 4th May	Thomas Klestil, President of Austria	*Tilia cordata*		Arboretum
1995, 13th March	Ali Hassan Mwinyi, President of the United Republic of Tanzania	*Quercus robur*		Arboretum
1995, 24th April	Árpad Gonсz, President of the Republic of Hungary	*Quercus frainetto* Ten.	Hungarian oak	Arboretum
1995, 15th November	Mr. Frederick Chiluba, President of Zambia	*Quercus robur*		Arboretum
1995, 1st December	Mr. Bill Clinton, President USA	*Quercus robur* [a]		Arboretum
1996, 23rd April	President Mary Robinson	*Quercus robur*		Arboretum
1996, 23rd April	Mr. Nicholas Robinson	*Quercus robur*		Arboretum
1996, 14th May	Martti Ahisaari, President of the Republic of Finland	*Sorbus aucuparia*	Rowan	Arboretum

1996, 28th June	Vaclav Havel, President of the Czech Republic	*Tilia cordata*		Arboretum
1997, 19th February	King Hussein of Jordan	*Quercus robur*		Arboretum
1997, 10th March	Robert Mugabe, President of Zimbabwe	*Quercus robur*		Arboretum
1997, 23rd March	Dr. Roman Herzog, President of Germany	*Quercus robur*		Arboretum
1997, 25th March	Aleksander Kwasniewski, President of Poland	*Quercus robur*		Arboretum
1999, 31st May	Dr. Jorge Sampaio, President of Portugal	*Quercus robur*		Arboretum
2000, January	President Mary McAleese and family	7 × *Laurus nobilis*	Bay laurel	Arboretum
2000, 4th July	President of Greece	*Quercus robur*		Arboretum
2000, 23rd October	President of Uganda	*Quercus robur*		Arboretum
2001, 24th September	President of Lithuania	*Quercus robur*		Arboretum
2002, 4th March	President of Luxembourg	*Quercus robur*		Arboretum
2002, 4th June	President of Latvia	*Quercus robur*		Arboretum
2002, 28th June	President of Nigeria	*Quercus robur*		Arboretum
2003, 16th June	King of Malaysia	*Quercus robur*		Arboretum
2003, 3rd July	President of Germany	*Quercus robur*		Arboretum
2003, 10th July	President of Chile	*Quercus robur*		Arboretum
2005, 21st February	President of Hungary	*Quercus robur*		Arboretum
2005, 12th December	President of Bulgaria	*Quercus robur*		Arboretum
2006, 31st May	Governor General of New Zealand	*Quercus robur*		Arboretum
2006, 18th September	King of Norway	*Quercus robur*		Arboretum
2007, 19th February	President of Poland	*Quercus robur*		Arboretum

Table 1: *Continued.*

Date	Head of State /Country	Name of Tree	Common Name	Location
2007, 26th March	President of Slovakia	*Quercus robur*		Arboretum
2007, 8th October	King of Belgium	*Quercus robur*		Arboretum
2007, 12th November	President of Finland	*Quercus robur*		Arboretum
2008, 14th April	President of Estonia	*Quercus robur*		Arboretum
2008, 10th November	President of Czech Republic	*Quercus robur*		Arboretum
2010, 8th March	José Ramos Horta, President of East Timor	*Quercus robur*		Arboretum
2011, 4th April	Prince Albert II of Monaco	*Quercus robur*		Arboretum
2011, 17th May	Queen Elizabeth II of England	*Quercus robur* "Fastigiata"	English upright oak	Bell
2011, 23rd May	President Barack Obama, USA	*Quercus robur* "Fastigiata"		Bell
2011, 4th November	President Mc Aleese	*Quercus robur* "Fastigiata"		Bell
2014, 3rd June	President Guebuza of Mozambique	*Prunus* "Kanzan"		Arboretum
2014, 6th October	President of Austria	*Prunus* "Kanzan"		Arboretum
2015, 3rd March	President Michael D. Higgins	*Cedrus atlantica* "Glauca"		Arboretum
2015, 3rd March	Mrs. Sabina Higgins	*Cedrus libani*	Cedar of Lebanon	Arboretum
2015, 13th July	President Gauck of Germany	*Quercus robur*		Arboretum
2016, 15th June	President Michael D. Higgins	*Quercus robur*		Arboretum
2016, 18th October	President Anastasiades of Cyprus	*Quercus robur*		Arboretum

[a] This Irish oak was eight years-old when planted.

Table 2: *Champion Trees in Áras an Uachtaráin, recorded on 31st August 2000 (from Tree Register of Ireland (8/9/2015), courtesy of Dr. Matthew Jebb, National Botanic Gardens).*

Name of Tree	Height (m)	Girth (m)	Height of measurement (m)
Aesculus hippocastanum Planted by Princess Victoria in 1904	16.4	2.27	1.50
Aesculus hippocastanum	24.2	4.38	1.50
Aesculus hippocastanum	23.7	4.69	1.50
Calocedrus decurrens	25.3	3.39	1.50
Cedrus libani	26.8	6.40	1.50
Fagus sylvatica. Planted by Princess Margaret in 1904	16.07	2.70	1.50
Fagus sylvatica. Planted by Prince Arthur in 1904	20.5	3.38	1.50
Laburnum anagyroides	10.5	1.15	1.06
Picea orientalis	24.4	2.68	1.50
Quercus ilex "Fordii"	15.3	2.07	1.50
Quercus robur. Planted by the King of Belgium in 1968	12.6	1.29	1.20
Sequoiadendron giganteum	29.0	4.90	1.50

Acknowledgements

The Tree Council of Ireland visit to *Áras an Uachtaráin* on 23rd June 2015. The Library, University College Dublin; Finín Ó Murchú, *Áras an Uachtaráin*; Margaret Gormley, Chief Park Superintendent, Phoenix Park; Dr. John Mc Cullen; Dr. Matthew Jebb, Director, National Botanic Gardens.

References

Anon. 1907. Irish international exhibition: the royal visit. *Irish Times,* 8th July 1907, p. 9.

Anon. 1991. President plants sapling. *Irish Examiner*, 6th November 1991, p. 24.

Anon. 2013. *Áras an Uachtaráin*. The Office of Public Works, Dublin, pp. 8–9 [Accessed November 2015].

Anon. 2015. President plants official tree at Áras an Uachtaráin. Available at http://treecouncil.ie/?s=President+plants+official+tree+at+%C3%81ras+an+Uachtar%C3%A1in [Accessed August 2015].

B. 1870. Notes made during a tour in Ireland, The Vice-Regal Lodge. Phoenix Park. *The Journal of Horticulture, Cottage Gardener, Country Gentleman, Bee-Keeper and Poultry Chronicle*, Vol. XIX, New series, 473.

Cooney, J. 1975. Visit to Jewish State recalled. *The Irish Times*, 2nd September , 1975, p. 6 [Accessed September 2015].

Donaghy, K. and Byrne, J. 2005. Emperor's sapling becomes tall Irish tree. *Irish Independent* 10th May 2005, p. 5. Irish Newspapers Archives [Accessed November 2015].

Fitzpatrick, H.M. Undated. *The Story of our Trees*. David and Anne Luke, Dublin, pp. 2–3.

Mc Cullen, J. 1993. A landscape history of the Phoenix Park, Dublin. In *Wild Plants of the Phoenix Park*. Reilly, P.A. Stationery Office, Dublin, p. 118.

Mc Cullen, J.A. 2009. *An Illustrated History of the Phoenix Park Landscape and Management to 1880*. Stationery Office, Dublin, pp. 208–212.

President's web site. Photograph of President Douglas Hyde planting the tree. Available at www.president.ie [Accessed November 2015].

Robinson, W. 1865. The Dublin Phoenix Park. *The Gardeners' Chronicle and Agricultural Gazette*. p. 75.

Tree Council of Ireland. www.treecouncil.ie [Accessed September 2015].

Dynamic silviculture – an alternative approach to traditional oak silviculture

John Fennessy[a*], Peter Savill[a] and Brian Clifford[b]

Introduction

France has a long tradition in the production of high quality hardwood timber, particularly from oak. Recently in France, the various forestry organisations involved in oak silviculture, including the association representing the private forest owners, the Centre National de la Propriété Forestière (CNPF), in cooperation with the Institut pour le Développement Forestier (IDF) and the state forestry organisation, Office National des Forêts (ONF), have through the establishment of a national oak working group, been examining ways to reduce rotation lengths while still producing the highest quality timber. While in the UK the "Free Growth" method has been explored through research trials commenced in the 1950s by Hummel (1951), by Jobling and Pearce (1977) in the mid 1970s and again by Kerr (1996) in the 1990s. In order for foresters working with oak to explore these methods two field trips were organised by Woodland Heritage, the first to Central France in November 2015 and the second to southern Britain in April 2016. This report provides a record of these trips and background on some of the newly developing production methods for high quality oak production, specifically dynamic silviculture -a new and rapidly changing oak silviculture.

Overview of traditional oak production in Central France

Forests cover approximately one-quarter of the land area of France – about 14 million ha, of which about two-thirds are broadleaved. Oak forests occupy about 34% of the total forest area (Teissier du Cros, 1987). A number of different species of oak are native to France. However, of them all, only pedunculate oak (*Quercus robur* L.) and sessile oak (*Quercus petraea* (Matt.) Liebl.) are important economically. They form a major component of the forests on the plains and lower hills of France, and in many other parts of Europe including Britain and Ireland. In fact, they constitute the major part of productive European broadleaved forests. Both species exhibit wide tolerance of ecological conditions and have many attributes in common. Both species retain the ability to react to increased growing space by crown development, even in old age (Joyce and Gardiner 1986). Sessile oak tends towards more mild and oceanic climatic conditions, so its share of the range diminishes in Northern and Eastern Europe. It is found at higher elevations than pedunculate oak. With less requirement

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for water, sessile oak is considered more suitable for drier sites, whereas sites for pedunculate oak are becoming more limited in France, and in the Central region the species is now considered to be at its ecological limit, due mainly to regular seasonal moisture deficits. Pedunculate oak is essentially a valley-bottom tree which performs best on deep, rich soils with ample moisture (land that is now mostly cleared for agriculture). Where moisture is lacking at crucial times during the growing season it will perform poorly and may even suffer dieback. On good sites both species can perform outstandingly well, provided the trees are given early and adequate space which suggests a requirement for early and heavy thinning. A critical consideration is that crowns of the best and most vigorous trees need to be given full sunlight as early as possible to allow complete development of the individual tree.

The traditional production cycle for high quality oak has been recognised in France for over a century and has been defined as the Méthode Française (Pardé 1986). This traditional silviculture usually extends over a rotation of at least 180 years, and sometimes up to 250 (Figure 1). While such long rotations are economically difficult to justify, even with the production of such high quality oak timber, they are still generally practised in both the public and private forestry sectors.

Because of the long rotation and the relatively low volume production, oak growing has only one objective: the production of the highest quality, high value logs for veneer and sawn timber for furniture-making, as well as for cooperage. Furthermore, the uses of oak timber has changed, and while stems with very narrow rings are still sought for particular products, wider regular rings are now used for joinery, sliced veneers, barrel staves and many other uses. Indeed, it appears that oak growing in France is going through something of a crisis, as traditional rotations are so long that the timber for cooperage is becoming increasingly hard to find. This is greatly exacerbated by the increase in demand for oak cooperage from wine growing regions other than France (for example Australia, Chile and New Zealand), all of which want French oak barrel material. Foresters in France have concluded that it is possible to grow high-quality oak in under a century – not a new discovery they say but a verification of past practices where oak was grown as standards over coppice. Lemaire (2010) concluded that a good approach is to modify the silviculture of open-grown crops to achieve such results.

New methods for the production of high quality oak wood in France

Up to the 1990s most of the forest sector in France made little or no distinction between the two oak species despite their different ecological requirements. The silviculture for both was identical, and restocking always by natural regeneration. However, today more stands are planted and new afforestation projects, such as farm woodlands, are generally established by planting or by sowing acorns. This is

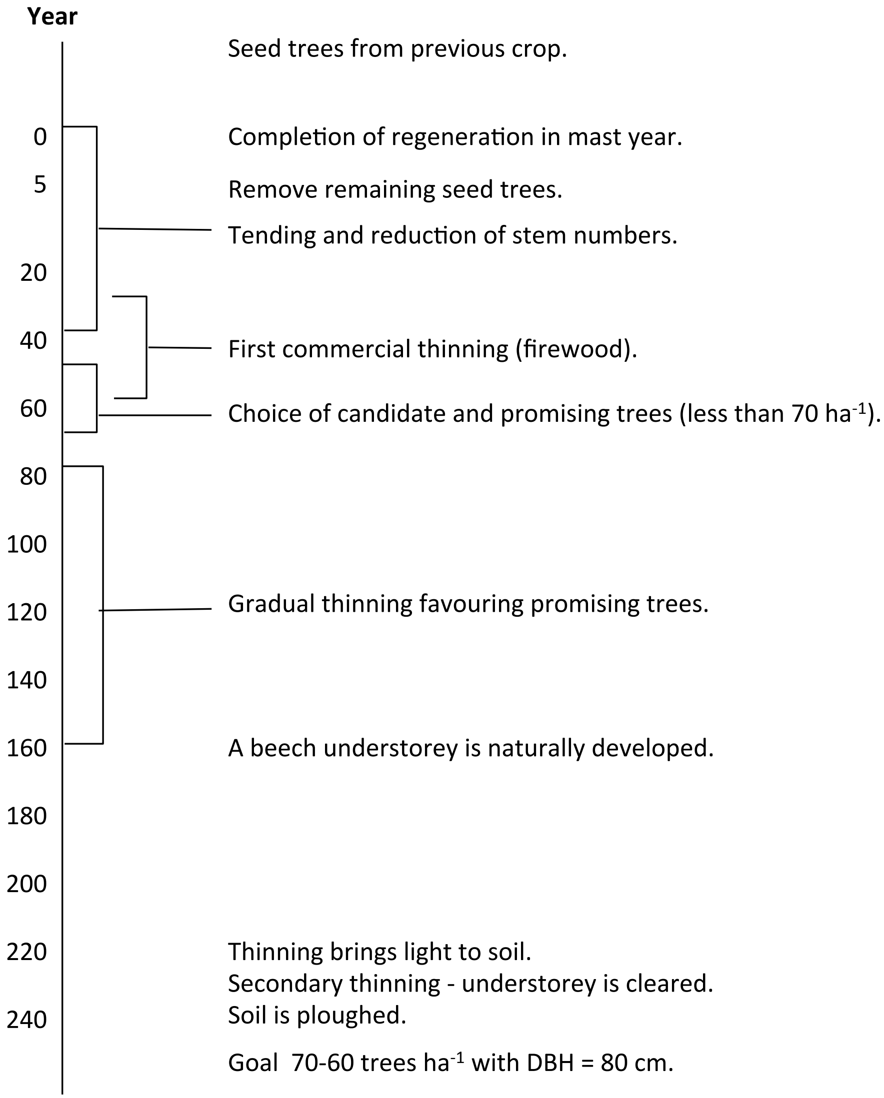


Figure 1: *Diagrammatic representation of the traditional French oak rotation, extending over more than 200 years (adapted from Teissier du Cros 1987).*

mainly due to the unsuitability of one or other oak species to features of certain sites, for example pedunculate oak was previously established where moisture deficits developed. Furthermore, where artificial regeneration was practised in the past, seed was often introduced from inappropriate sources, e.g. from outside France. Many of these were from locations such as the Netherlands or, surprisingly, even Britain. However, around ten to fifteen years ago extensive dieback and even some mortality of mature oaks were observed by forest owners which caused a great deal of alarm (Figure 2). When the cause was investigated it was found to be related to seasonal moisture deficiencies. This was especially the case with pedunculate oak stands. This led to a re-examination of the requirements and the differentiation of both species as well as an examination of both species specific site requirements.

The various forestry organisations involved in oak silviculture, including the association representing the private forest owners in France, the Centre National de la Propriété Forestière (CNPF), in cooperation with the Institut pour le Développement Forestier (IDF) and the state forestry organisation - Office National des Forêts (ONF) - have, through the establishment of a national oak working group, been examining ways to reduce rotation lengths while still producing the highest quality timber.

In the 1980s, an oak study group was formed in the central region of France, the main area for the production of high quality oak. The study group has undertaken an extensive series of field trials, organised seminars along with regional meetings and facilitated a number of local and regional groups to examine ways of achieving a substantial shortening of the traditional oak rotation. The culmination of their work has been a far-reaching report on a method of silviculture based on the individual tree, and termed "dynamic silviculture", containing a suite of recommendations which if implemented lead to a substantial reduction in rotation length. The report

Figure 2: *Pedunculate oak in France showing the effects of water stress. (Photo: Bede Howell.)*

was published in 2010 as *Le chêne autrement: Produire du chêne de qualité en moins de 100 ans en futaie régulière* (Lemaire, 2010). It was translated and published by the Future Trees Trust in 2014 (with support from Woodland Heritage, UK and the Department of Agriculture, Food and the Marine in Ireland). The translation was undertaken by Bede Howell OBE, an eminent forester with extensive experience with oak silviculture in Britain as well as having worked on oak management in France, and published as *Oak: fine timber in 100 years - Growing high-quality oak within a century* (Lemaire 2014).

This method of silviculture, based on the requirements of the individual tree, consists of selecting the best trees for the future – referred to as "winners" – the most vigorous, well-formed trees; all effort is concentrated on bringing these trees to a marketable size in 100 years or less. Work includes re-spacing, thinning, pruning and other management. Selection of the individual trees is made as early as possible, usually at time of first thinning when the top height is between 9 – 12 m. Sometimes it may be necessary to re-space, especially in naturally regenerated stands, at a height of 3 m and possibly again at 6 m. If necessary, the winners are pruned when they have been selected.

Free growth is not a new idea. It was evaluated in Great Britain by Forest Research through silvicultural research trials in the 1950s (Hummel 1951). However, coniferous forestry was much more important at that time and there was little emphasis on broadleaves which resulted in little if any follow-up of this silvicultural system. More recently Jobling and Pearce (1977) revisited the method in the mid 1970s but again at that time conifers dominated and the method remained overlooked. Evans (1984) also presented a diagrammatic response of diameter increment to free-growth. Later Kerr (1996) undertook a further evaluation of this system. A summary of findings at the time showed that:

- there is a close relationship between the average crown diameter and DBH (basal area) in oak and all other species, irrespective of age and the rates of height and radial growth (Dawkins 1963, Hemery et al. 2005, Kerr 1996).
- timber height in free-grown oak is usually low. To obtain a satisfactory length of clean bole, green pruning is usually necessary.
- free-grown oak has a substantially faster rate of radial growth than oak in traditional high forest.
- the crop parameter least affected by free-growth is total tree height.
- by contrasting the information on the relationship between crown diameter and DBH with rate of growth (age/height and age/DBH) a preliminary yield table can be constructed.
- a very small number of young trees, no fewer than 1,600 ha^{-1}, is considered adequate to achieve complete stocking at maturity.

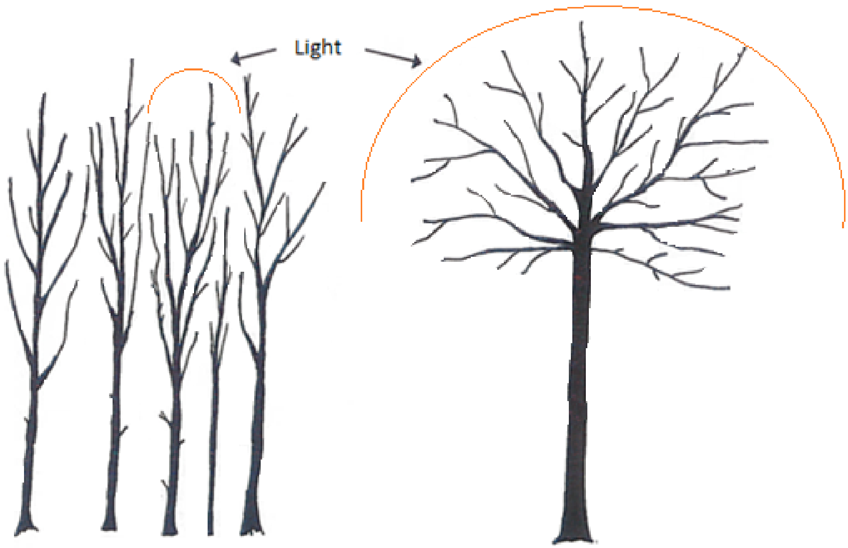
More recently in Ireland the free-growth silvicultural system has been evaluated by Short (2013) in the context of poorly performing pole-stage broadleaf stands and he has recommended that the system be considered for a number of broadleaf species including oak. These findings concur with new findings from a recent French study (Le Nail 2015) and are the basis of much of the shorter, production cycles that are now practised in new dynamic French oak silviculture. Despite this the free-growth approach for oak has been questioned due to the additional labour required to control epicormic shoots and may be more suited to species such as ash or sycamore (Kerr 1996). However, a study by Beinhofer (2010) modelled the free-growth system, with and without pruning, and compared it with conventional management. Results from the modelling excercise showed that oak grown under the free-growth system and pruned, provided better financial returns than conventionally grown oak or un-pruned free-growth oak (Short 2013).

The close relationship between average crown diameter of free-grown oak and DBH, irrespective of age and the rates of height and radial growth, are very important. French researchers have focused entirely on this particular aspect (Figure 3). Of course, because the stand density is much reduced, total production over the rotation is also reduced, but the economics of the enterprise might be greatly improved due to a much shorter rotation.

Today the accepted standard is to have an initial stocking of 1,600 trees ha^{-1} at time of establishment. The initial stocking of the stand illustrated in Figure 4 was 15,000 ha^{-1} but it was reduced to 10,000 ha^{-1} at the end of first year due to natural mortality and predation. Further reductions were achieved by removing unwanted stems, cutting at approximately 1.5 m in height. At a top height of 3 m the stocking was further reduced to 1,600 ha^{-1}. The stand is now 19-years-old.

Study visit to forests in Central France

In November 2015, Miles Barne of Sotterley Estate, Suffolk, England, and Peter Goodwin of Woodland Heritage arranged for an invited group of Irish and British foresters and forest owners to visit the main French oak-growing region to examine the new oak silvicultural system at first-hand, meet the researchers and to visit some of the field-trials. The visit also presented an opportunity to meet some of the French forest owners who advocate and now practice the new system. During the visit it was possible to contrast the new system with the traditional French production method. The visiting group consisted of foresters, researchers, students and forest owners from Great Britain and Ireland who are actively involved in oak silviculture and provided them with a valuable opportunity to spend a few days in this important oak-growing region as guests of the Centre National de la Propriété Forestière (CNPF). The group assembled on Sunday afternoon (1st November 2015) in Tours in the Loire valley where the visit was based.



Left – small crowns of plantation oak
- 25-year-old trees, not thinned and crowded;
- Many defects e.g. forks and knots;
- Profuse epicormics shoots when thinned;
- Wood production of very poor quality;
- Likely rotation: 150 – 180 years at least, if not more.

Right – large crown of "free-grown" oak
- 25-year-old tree in a plantation and thinned 2 – 3 times;
- Bottom log of 5.5 – 7.5 m length, without defects;
- No or slight risk of epicormics shoots;
- High quality timber, particularly the bottom log;
- Likely rotation: 80 - 100 years.

Figure 3: *Idealised contrast and comparison of development of constrained (in plantation) and non-constrained (free-growth) crowns of oak (adapted from Le Nail 2015).*

Monday 2nd November -morning

The group met French forestry colleagues including Eric Severin (Deputy Director, CNPF in Pays de Loire) who arranged the programme, provided leadership for the group and acted as tour leader for the duration of the visit. The group travelled north towards Le Mans and from there to private oak plantations close to Chémeré-le-Roi and Saint-Loup du Dorat. Here the group visited a private forest owned by M. Le Nail, who was on site to welcome the group and to discuss his forest stands and their management issues. M. Bruno Longa and M. Christian Weben, both colleagues of Eric Severin at CNPF, also joined the group at the site.

In the 1980s, agriculture in France was experiencing low prices for most products combined with over-production and generally poor economic returns, similar to the situation in Ireland and the UK at the time. This resulted in some farmers like M. Le Nail deciding to change from the traditional agriculture of mainly corn tillage (maize) to an alternative enterprise. He converted his estate to forest, with particular emphasis on the production of high quality oak. M Le Nail's experience with maize production also guided him at the time of establishment of his new forests and suggested that the best time to sow acorns would be in the spring rather than the autumn; with reduced predation establishment rates would be improved. Early findings from a number of trials supported this and sowing in April/May at a rate of 100 kg acorns ha^{-1} resulted in the establishment of 15,000 plants ha^{-1}. There were many variations to this method, depending on the owner, but they all had the same objective: to shorten the very long traditional French oak rotation (see Figure 1).

First stop

Pays de Loire are renowned for the high quality of oak produced there. The conventional rotation is generally at least 180 (and sometimes up to 250) years. This is now considered much too long and uneconomic by private owners as well as by the state foresters, so other methods had to be explored to seek to shorten such a long production cycle. One area focused on was the very fast growth of individual

Figure 4: *Stand stocking reduced from very high numbers to the current 1,600 stems ha^{-1}.*

oak trees in traditional oak silvicultural systems such as coppice-with-standards and also oak established in hedgerows. Various studies have suggested that in hedgerow conditions, it was possible to produce large trees over a much shorter rotation and the oak produced had a lighter and flatter branching habit. This was especially the case where individual trees were allocated fully open area for crown development without impediment. It suggested that free-grown oak could produce large trees in a much shorter time. Studies also established that, when compared with conventionally thinned oak, the basal area (BA) of open-grown trees could be as much as double that of traditional oak trees of the same age.

Second stop

The second stop was also on Mr Le Nail's estate, again at a 19-year-old oak stand produced from acorns sown as at stop 1. The stocking of that stand had been reduced to 2,200 trees ha^{-1} at 3 m height. The second reduction to 1,200 stems ha^{-1} occurred

Figure 5: *Selected "winners" (potential final crop trees marked with red paint bands) at 120 stems ha^{-1}. Note the openness of the stand and low the stocking at 24 years of age.*

when a top height of 5 m was attained. The stand now has only 120 trees ha^{-1} and will be thinned every four years. After the first thinning a high pruning was also undertaken. It is anticipated that by age 45 the stocking will be approximately 60-70 trees ha^{-1}, with an anticipated rotation of about 90 years.

<u>Third stop</u>

The third and final stop of the morning was also on Mr Le Nail's estate (Figure 5). The stand, which was 24 years-old, was first thinned at 6 m top height. The final crop will be 70 trees ha^{-1} at age 90 when the expected DBH will be 60 cm, though some trees may be up to 80 cm DBH.

It is also planned that this stand would be thinned every four years, in contrast to the original plan which was to thin every 8 to 10 years, as the increased production requires much more frequent thinning. At that site M. Le Nail hopes to have a stand reflecting an "active" silviculture approach by 40 years of age.

Monday 2nd November –afternoon

For the afternoon the group travelled to another private forest in the vicinity of Sablé-sur-Sarthe where a number of adjoining stands of oak were visited. The first was planted at 2 × 2 m in 1983/84 and was aged 31 years. It was first thinned in 2000, with further thinning in 2004 and 2008, and most recently in 2013. Current spacing is between 8 and 12 m between selected "winners". Again this stand was quite impressive for its age and was also responding well to the early and frequent thinning.

The next stop was in an oak stand which was planted in 1993. It contained an experimental area where two contrasting treatments were being tested. The first was a stand managed using active silviculture (Lemaire 2010) and the second where no thinning had taken place. While the performance of the selected "winners" was impressive, it was not as outstanding as the stands visited in the morning, however the overall performance was still outstanding.

Tuesday 3rd November -morning

The group travelled along the valley of the Loire passing the town of Vouvray with its fine château en route to the 4,000 ha Forêt D'Amboise, one of the oldest oak forests in France. This area is considered one of the most suitable areas for high quality oak production; the oak forest is recognised as the finest in all of France. While much of the oak was pedunculate in the past, today the species is only planted on a limited scale as it is now considered to be at its limit due to seasonal droughts.

<u>First stop</u>

At the first stop the group was introduced by Eric Severin to the local leaders for the day, Mme Laurence Degoul (UNISYLVA) and Franck Masse (CNPF) along with

M. Laurent Borel (Forester-in–charge) and M. Renaud. A short introduction to oak production in the forest was provided. Despite having a long tradition of growing high quality oak, the traditional cycle, as was also highlighted on the previous day, is now considered too long from an economic viewpoint, and so methods to shorten it are now being introduced.

Second stop

Our next stop was in a 33-year-old oak plantation. The original spacing was 1.5 × 1.5 m in small gaps. The plants used were seedlings collected in the locality (where the genetic quality was considered excellent). The height of seedlings varied between 25 and 40 cm. The rotation there was 120 years. A naturally regenerated hornbeam nurse had been used, which is considered an economically valuable understorey. Current heights range between 15 and 18 m and selected "winners" were spaced wide apart (Figure 6).

Figure 6: *Selected final crop trees – the "winners" marked with green bands.*

Near this site we also saw a naturally-regenerated 15-year-old oak stand which had a number of gaps, but where two very large gaps existed, acorns had recently been sown to achieve full stocking. Establishment costs varied between €3,000 and €5,000 ha^{-1} for oak whether by natural regeneration or planting. Natural regeneration generally results in faster establishment but if the site is considered unsuitable for the species than replanting is the only option. For instance where naturally regenerated pedunculate oak is unsuitable due to developing water deficits (Figure 2) the trend is to replant these areas with sessile oak. During the very early stages it is also important to maintain competition. At this time the most vigorous individuals ("winners") begin to develop dominance.

Other stops

During our visit to the Forêt D'Amboise the importance of "dynamic silviculture" in the production of high quality oak was demonstrated. It involved:

- planting at least 1,600 stems ha^{-1} and allowing the most vigorous individuals to express their potential, sometimes even disregarding straightness and overall quality.
- selecting 70 to 80 vigorous, well formed "winners" ha^{-1} at the time of first thinning, when the stand reaches between 9 to 12 m. Selected trees are bigger than average, where girth is approximately 20% greater than the mean of the surrounding trees.
- trees selected should be free from defects such as broken crowns, stem damage or pronounced curves in stem.
- there should be not more than three large branches on the first five metres of stem.
- allowing full crown development of the winners through regular "halo" thinning.
- at first thinning stage removing between 35 and 40% of the standing volume.

The ultimate target was 70–80 trees ha^{-1} at 90 years – which was the anticipated end-point of the shortened rotation.

Methods for sale of oak logs in France

Having seen many different sites where dynamic silviculture of oak was now the norm, the group then visited a site where logs were being prepared for a roadside log auction (Figure 7).

Since the 1990's the demand for small oak barrels, commonly known as barriques with a capacity of 59 gallons (225 l) has increased substantially (Dominé 2001). In most of the world's wine producing countries, an ever increasing number of winemakers are using these barrels as vessels to vinify white and red wines. Oak from a number of sources is used to make these barrels but French oak is considered the very best material to use.

Figure 7: *Oak logs prepared for an auction in the Forêt D'Amboise. Each log was marked to identify the specific sale lot.*

In France logs are usually sold at auctions held regularly throughout the year. The quality of oak depends on (1) colour, (2) ring width and (3) length of log. Another factor considered for barrel-making is the tannins which impart a particular taste to wine. From their experience in sourcing oak wood in the region, certain stands are noted by buyers for their desirable wood tannin characteristics, imparting a sweet taste to the wine, while others are noted for wood which imparts a bitter taste. The most desirable stands are well known in the trade. The wood lots with the desirable taste are much sought after by timber merchants. For cooperage a log of at least 40 cm in diameter and free of defects is required and with a length of 1.1 m. Prices vary quite considerably but on average the highest quality logs sell for between €400 – 600 m^3, second quality for €300 – 500 m^3 and the lowest quality for €150 – 250 m^3 (L. Degoul, 2015, pers.comm.) A detailed catalogue is prepared for each auction and extensive details of each log are provided. The quality of the logs on display in the forest varied considerably. Many were fairly crooked and had what appeared to contain several defects, nevertheless one got the impression that they were prime logs from a timber quality point of view. The quality of logs seen in the sawmill which the group visited later was also quite variable. This was somewhat reassuring for the group as we expected to see only premium quality logs in France and not such a wide range of grades and types.

Tuesday 3rd November -afternoon

After lunch the group visited a specialist oak sawmill, Scierie Besson at Beaumont. This mill produced green oak beams, air-dried oak beams, square-edged oak, oak boules, oak railway sleepers and boule logs. It saws approximately 10,000 m^3 per annum, mostly oak, with some smaller quantities of Douglas fir also.

Wednesday 4th November -morning

During the final morning the group visited another private forest in the vicinity of Vallières-les-Grandes with a stop in a stand of sessile oak planted in 1994/95 at 1,736 plants ha^{-1}. The site had been excellent agricultural land which grew corn in the recent past. The stand had been planted in strips 4 m wide, each with six rows within strips. Planted strips alternated with 3 m wide unplanted strips (Figure 8).

In an adjoining part of this stand the group (divided in two) performed a hands-on exercise. The purpose was to get a feel for the practical application of "dynamic silviculture". The first group were given the task of selecting "winners" while the other group were required to mark the "halo" thinning around the selected trees. The general tendency was for the groups not to mark enough trees for removal. For an example of halo thinning see Figure 9.

Figure 8: *A young stand of sessile oak on former agricultural land close to Vallières-les-Grandes.*

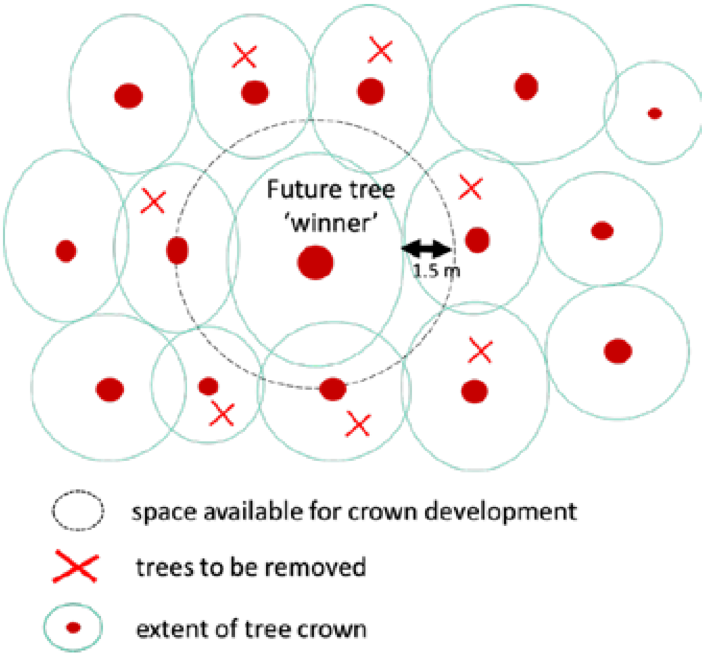


Figure 9: "*Halo*" *thinning (adapted from Anon. 2015).*

UK free growth oak study tour - April 2016

A follow-up tour took place on the 20th and 21st of April to the UK, organised by the Woodland Heritage. The aim of this tour was to expand on the lessons learned in France and discuss the merits of "free grown oak" and "active silviculture" in a British and Irish context. The tour took in two sites, the first a Forest Research experimental site at Crumbland, Wales and the second, a visit to the Cranborne Estate in southern England where a somewhat similar thinning regime as per the Lemaire (2014) methodology had been implemented.

Day 1: Crumbland, Gwent, Wales.

The Crumbland plantation is located in Tintern Forest, Gwent in Wales where the soil may be described as a well drained loamy brown earth over old red sandstone. Slope was slight to moderate with a south easterly aspect, moderate exposure and rainfall of approximately 960 mm per year. The stand was established by planting in 1931 with the plants raised from seed of an unknown origin. It was originally planted at a very high spacing of 1.2 × 0.6 m (13,888 ha^{-1}). The experiment was established in 1950, at age 19 with three original treatments applied and 10 replications of each treatment. These included: A) no thinning, B) crown thinnings, and C) free-growth. The objective of the experiment was to establish by how much the girth increment of selected predominants could be increased, above that obtained under conventional thinning following customary practice. However, due to the small size of the plots the treatments began to overlap and in 1964 it was decided to abandon treatments A and B and convert them to free-growth treatment (C). The free-growth approach involved selecting approximately 80 final crop trees evenly spaced throughout the stand, carrying out a very heavy first thinning and second thinning (Figure 10).

The benefits of the free-growth approach were reported as:

- trees producing a high value crop on shorter than normal rotation lengths have been shown to more than compensate economically for the reduction in yield;
- following thinning to allow free-growth, crown diameter increases, and there follow substantially enhanced rates of stem diameter increment compared with trees in conventionally stocked plantations.

Figure 10: *Selected final crop tree in the foreground being measured for DBH. Note the cleanness of the stem and the size of the crown. The "free grown" oak is high pruned to 5 m and given full space for crown development, which in turn leads to rapid radial growth.*

Non timber benefits:

- "more aesthetically pleasing";
- increased light on the forest floor resulting in a more prolific shrub and small tree layer;
- Lower bole may be rendered less susceptible to squirrel damage since without branches there is nowhere for them to perch;
- The percentage of heartwood produced by free growth treatment was not significantly different to that of a crown thinning (Kerr 2008).

The reduction in number of stems per ha results in more light being made available along the trunk and thus the likelihood of epicormic branches forming (Figure 11). As only a few stems are selected as the winning final crop, it is essential that they are of a very high quality, i.e. veneer or planking quality. Epicormics seriously reduce this potential. The importance of maintaining the remaining matrix trees and not pruning

Figure 11: *Selected final crop tree. Note the presence of epicormic branches.*

them was identified as being important to increase the possibility of shade along the trunk, as was the encouragement of an under-storey.

Final crop trees are selected and favoured at 8 m. Basel area of the stand is thus decreased to such an extent that revenue from intermediate thinning will be forgone later on in the rotation. Therefore in order to make the approach viable a quality product must be produced at the end of rotation.

A discussion took place around the amount of sap wood and whether faster grown oak would result in a reduction in quality. The consensus appeared to be that, 1) fast grown timber was not an issue, rather variation in growth rates could be problematic; leading to irregular growth rings and increased flow in sap which in turn may increase the probability of squirrel damage. 2) A "slow down" period was suggested by a number of attendees. That for a target diameter of 60 cm DBH, a further 10 -15 cm in DBH may be required to allow the heartwood to develop; and result in more planking or indeed veneer quality timber being produced.

Day 2: Crichel Down and Cranborne Estate, England

On the second day the focus switched to the active silviculture system as described by Lemaire (2014). The first stop was at the Crichel Down Estate where we saw a very impressive 7.3 ha block of sessile oak with a hazel understory, planted in 1954 (Figure 12).

Figure 12: *Sessile oak (62 years), originally planted in a mixture with Corsican pine. Elite oak trees were selected at year 16. Pine was thinned and finally removed at year 29. Oak was high pruned to approximately 5 m. The mix proved to be successful. Key to this success was appropriate thinning and final removal of pine. Also note the development of a hazel understory.*

The area was originally planted in four regular blocks and four mixture types according to Table 1 below. Conifers were thinned normally and oak was regularly pruned until eventually all conifers were removed.

Using conifers as a nurse species proved to be a relative success. However, this was attributed to the active management on the site. Without this the likely result is that the oak would have become suppressed. Thinnings were carried out regularly and oak were high pruned. Maintaining a basal area of between 15 and 18 m^2 was deemed optimum in order to encourage even growth and the development of an understory. Indeed the stand has a well developed understory of hazel which shades the most valuable part of the stem, thus preventing epicormic shoot development. The site management was therefore largely in line with that proposed by Lemaire (2014).

A very interesting graph was presented by the forest manager, Andrew Poore where the "active silviculture" thinning prescription was presented alongside that of the "free growth" prescription (Figure 13). This graph demonstrated effectively that key to the active approach is the careful management of stand basal area. According to the active approach stand basal area is maintained at between 15 and 18 m^2. This is achieved by re-spacing the stand to between 1,100 and 1,500 stems ha^{-1} at a height of 6 m and then by thinning every six years up to 16 m, every 8 years from 16 to 22 m, every 12 years from 22 to 26 m, and every 15 years thereafter. At each stage, the basal area is reduced to keep it within the prescribed range. This approach provides a steady stream of income while maintaining ground conditions such that the understory of hazel is developed. While the free growth approach prescribes a heavy first thinning in the early life of the crop and progressively reducing the basal area to 6 m^2 through a series of thinnings to age 50, or a top height of approximately 19 m. At this point no further thinning is carried out and the stand is managed to clearfell. There are clearly drawbacks to this both in terms of the management of epicormics, and in terms of cash flow for the remainder of the rotation.

Table 1: *Overview of species, planting arrangement and management prescription used at the Crichel Down Estate, UK (Poore 2016). SO = sessile oak.*

Species	Arrangement	1st thinned & oak pruned	Conifer removed	Age
Norway spruce (NS)	3:3 row NS 6ft × 6 ft; SO 3ft × 4 ft	1968	1996	42
European larch (EL)	Matrix of EL at 5 ft × 5 ft l SO in groups of 13, groups at 30 ft spacing (120 ha^{-1})	1965	1979	25
Corsican pine (CP)	4:2 row CP 5ft × 5ft; SO 3ft × 4ft	1965	1983	29
Japanese larch (JL)	Matrix of JL at 5 ft × 5 ft; SO in groups of 13, groups at 30 ft spacing	1965	1983	28

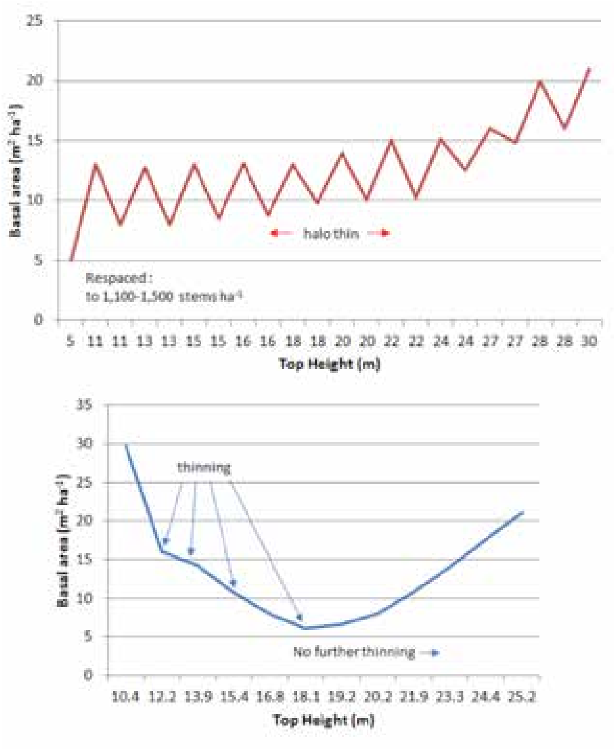


Figure 13: *Thinning regime of active silviculture (top) vs. free growth (bottom). Adapted from Poore (2016).*

Conclusion

The dynamic system of growing oak in France is one which merits greater attention by British and Irish oak growers. The findings of studies undertaken by Forest Research in the UK since the 1950's would also support this. The main elements of these findings are:

- at first establish whether a potential site is suitable for the oak species proposed – pedunculate or sessile oak depending on availability of soil moisture. This issue may not be as important for British or Irish oak growers as moisture deficits are relatively infrequent, but in parts of France, seasonal moisture availability is now becoming a very important and decisive issue regarding oak species suitability;
- plant at least 1,600-1,700 stems ha^{-1} at time of establishment using the very best and most suitable provenance available. Where stocking is high the stand is thinned at three metres to reduce to the previously stated stocking;
- stand allowed to develop until it reaches a height of 9 – 12 m. Manual cleaning carried out during this time depending on site conditions;

- identify the "winners" at as early a stage as possible;
- between 9 and 12 m the canopy closes and natural pruning takes place. Even at this stage oak may naturally re-absorb some forks and large branches. However, some of the potential crop trees (winners) may need to be pruned;
- choose only the most vigorous trees as "winners". If they are slightly crooked remember that oak has capacity for straightening to some extent during early growth;
- allow the selected "winners" complete crown space by "halo" thinning;
- remove heavy branches from the winners and even occasional forks where necessary;
- aim for a rotation of 90 - 100 years.

The dynamic system which is now being applied in certain areas of France, especially in the private sector, merits greater review, analysis and possibly a new research programme to test such methods in Britain and Ireland. This is a task of such importance for future oak silviculture in this region that the Oak Group of Future Trees Trust must now consider, discuss and possibly look to the establishment of similar trials in both countries in the near future.

The free-growth method may also prove useful for other broadleaf species such as sycamore and ash, as has been suggested by Kerr (1996, 2008) and Short (2013). However, for oak it would appear that the opening up of the stand to the degree prescribed at such an early stage of the rotation, will result in a significant issue of epicormic branching which will limit its viability.

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References

Anon. 2015.

. Centre National de la Propriété Forestière (CNPF), 36 Avenue de la Bouvardière, 44800 Saint-Herblain, France.

Dawkins, H.C. 1963. Crown diameters, their relation to bole diameters in tropical forest trees. *Empire Forestry Review* 42, No. 114: 318–33.

Dominé, A. 2001. *French Oak Forests* (In Wine). Konemann Verlagsgesellschaft mbH, Bonner Strasse 126, D-50968 Cologne, Germany.

Evans, J. 1984. *Silviculture of Broadleaved Woodland*. Forestry Commission Bulletin No. 62. HMSO, London.

Hemery, G.E., Savill, P.S. and Pryor, S.N. 2005. Applications of the crown diameter - stem diameter relationship for different species of broadleaved trees. *Forest*

Ecology and Management 215: 285–294.

Hummel, F.C. 1951. *Increment of Free-grown Oak*. Report on Forest Research. 1951. Forestry Commission. HMSO, London.

Jobling, J. and Pearce, M.L. 1977. *Free Growth of Oak*. Forestry Commission Forest Record No. 113. HMSO, London.

Joyce, P.M. and Gardiner, J.J. 1986. The management of oak in Germany: a silvicultural note. *Irish Forestry* 43: 56–65.

Kerr, G. 2008. *Crumblands Free Growth Area. A Brief Guide*. Forest Research Station. Alice Holt Lodge, Farnham, Surrey GU10 4LH.

Kerr, G. 1996. The effect of heavy or "free growth" thinning on oak (*Quercus petraea* and *Q. robur*). *Forestry* 69: 303–317.

Lemaire, J. 2010. *Le Chêne Autrement*. IDF (Institut pour le développement forestier), p 176.

Lemaire, J. 2014. *Oak: Fine Timber in 100 Years*. IDF (Institut pour le développement forestier). Translated by Bede Howell. Future Trees Trust.

Le Nail, B. 2015. Et si l'on osait querciculture? *Forêt-entreprise* 223: 7–16.

Pardé, J. 1986. Naissance et dévelopment d'une sylviculture européenne commune. *Annales de Gembloux* 92: 87–110.

Poore, A. 2016. Woodland Heritage visit to Crichel Down/Cranborne Estate, 21st April 2016. SelectFor Ltd., The Old Dairy, North Bowood, Bridport, Dorset DT6 5JH.

Short, I. 2013. The potential for using a free-growth system in the rehabilitation of poorly performing pole-stage broadleaf stands. *Irish Forestry* 70: 157–171.

Teissier du Cros, E. 1987. The French approach to broadleaved silviculture. *Irish Forestry* 44: 116–126.

Trees and woodland names in Irish placenames

John Mc Loughlin[a*]

The names of a land show the heart of the race,
They move on the tongue like the lilt of a song.
You say the name and I see the place
Drumbo, Dungannon, Annalong.

John Hewitt

Since trees are very visible in the landscape, it is not surprising that so many of our placenames have derived from trees and woods. Today, if a forest was to spring up everywhere there is a tree-associated name in a townland, the country would once more be clothed with an almost uninterrupted succession of forests. There are more than 60,000 townlands in Ireland and it is estimated that 13,000 or 20% are named after trees, collections of trees (e.g. grove) and the uses of trees. Prior to road signs, with which we are so familiar today, natural and manmade features were the only directional sources. Placenames have been evolving since the dawn of Irish civilisation when most of the country was heavily forested and trees had a prominent role in the economy. Trees provided raw materials, medicine, weapons, tools, charcoal, food (in the form of berries, nuts, fungi, fruit, wild animals, etc.), geographical markers as well as the basis for spirituality and wisdom.

It is difficult for us today to interpret the origins of some of our placenames; they are derived from old Irish interspersed with Viking, Norman, and Medieval English influences, and in the north of the country Scots Gaelic also adds its influence. Mac Giolla Easpaig (2016) estimates that 90% of our placenames may have Gaelic origins. Many placenames have reverted to their original names, e.g. King and Queen's counties are now Offaly and Laois, and Kingstown and Queenstown are Dún Laoghaire and Cobh. Similarly, Maryborough and Newtownbarry became Portlaoise and Bunclody. Planters introduced names for their great estates from the 17th century from the neighbouring island. Since the Ordnance Survey began in the 19th century scholars have been using old manuscripts to interpret the origins of our placenames. A further difficulty was that when the scholars were recording the townland names, in many instances the origin was from oral tradition which introduced further inconsistencies. Today, the Placenames Branch, is continuing the work of deciphering the origins of our townland names.

Fergus Kelly in reviewing the Old-Irish law texts from about the eighth century AD, found that there were four divisions of trees and that the fine or penalty for cutting a

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tree was commensurate with the division the tree was in. These texts give provide an indication of how important and how prevalent trees were in that period. In the first category includes the important trees, called "Nobles or Lords of the wood", which carried the highest fine. This category comprised ash, crab apple, hazel, holly, oak, yew and Scots pine. The inclusion of Scots pine as a noble is interesting as it could indicate that it was still abundant in the 8th century. In the next category, "Commoners of the wood", were alder, birch, cherry, elm, hawthorn, rowan and willow. All these trees are well represented in our townland names. In the next category, "Lower Divisions of the wood", were arbutus, aspen, blackthorn, elder, juniper, spindle and whitebeam. Juniper, spindle and whitebeam are not represented in townland names. "Bushes of the Wood" was the final division, which included bracken, bog-myrtle, furze, bramble, heather, broom and the wild rose. These shrubs were important for their fruits or as animal fodder or bedding. The addition of bog-myrtle is surprising but it could have been important for medicinal purposes, it was used in beer making before hops came to be used extensively. It could also have been important because of its ability to ward off insects. Native species absent from this list include alder-buckthorn, common-buckthorn, dogwood, Guelder rose, ivy, privet, spindle, honeysuckle/woodbine and whitebeam. However, honeysuckle and ivy are represented in townland names. According to Kelly (1999) woodbine, which was valuable as a substitute for rope, was absent but replaced arbutus in some lists. A review from this period provides an indication of the economic importance of trees as a wood supply and as food for humans and animals. Today, forests and woods are generally seen as supplying wood products only. Modern day foresters may find it difficult to understand how something as unimportant as briar could feature so significantly in townland names, whereas Scots pine is seldom featured. One assumes this is because the briar produced edible fruits.

No distinction was made between silver birch and downy birch or between bird cherry and wild cherry, although they have two distinct names in Irish -*dronnroisc* and *silín*. Neither is there any distinction made between pedunculate oak and sessile oak or between the two species of furze, European and Irish. Similarly *Caluna vulgaris* and the *Erica* species are not distinguished, having the same Irish name *fraoch*. Perhaps the reason that no distinction is drawn between trees, shrubs and climbers is that they were all equally important for survival.

The Ogham alphabet provides some useful insight into the importance of trees in earlier times when townland names were being developed. Ogham is the ancient Irish alphabet and many examples of it are still to be found on standing stones throughout the island. These inscriptions date mainly from the 3rd to the 5th century AD. Trees figured largely in the naming of the Ogham letters. The Ogham alphabet had twenty letters whereas today's Irish alphabet has just 18 letters -j, k, q, v, w, x, y, and z being absent. Originally eight letters were named after trees -alder, ash, birch, hazel, oak, Scots pine, willow and yew. Their selection suggests clues as to the importance of these trees to early Irish society. All of these trees also feature strongly in townland names. Scholars in the Middle-Ages built on the prominence of tree names in the alphabet and read other tree names into the remaining letters, resulting in a tree alphabet. The list which was compiled in the 3rd to the 5th centuries is similar to that compiled from the 8th century manuscripts. In addition to the eight species mentioned previously, twelve more were added which included apple, aspen, blackthorn, bramble, broom, elder, furze, hawthorn, heather, holly, ivy and rowan.

The Ogham tree alphabet became so intertwined with Irish tree folklore that, even though many of the tree/letter associations were the fabrication of medieval scholars, no treatment of the townland names would be complete without mentioning it. Ogham is read from right to left and from the bottom upwards -like climbing a tree.

Townlands are the smallest division of lands in Ireland, and were, at one time, owned by a family or tribe. Townlands vary in size; they can extend to more than 800 ha in the poorer mountainous areas whereas in areas with good agricultural land they tend to be much smaller, generally less than 40 ha. According to Mc Cracken (1971), there are 1,200 townland names containing oak in the Gaelic format *dair*. Two counties, Derry and Kildare are named after the oak. County Mayo is named after the yew. Surprisingly, yew is the second most numerous tree in placenames. Today, hawthorn is the most commonly occurring native species according to the National Parks and Wildlife National Inventory (2008). County Roscommon, *ros* is a Gaelic word for wood in the south, in the north *ros* is a peninsula, while County Monaghan derives from the little shrubbery in Gaelic. This results in our having five of our county names derived from trees and woods.

By the groves of Carhan river and the slope of Bin'a Tí.
Where the Boy of Bar na Sráide hunted for the wran.
Sigerson Clifford

Native trees and shrubs in townland names

This is only a sample of the names as a full gazetteer is not possible here A full list of native trees, including common, Irish and scientific names is included in Table 1.

Alder, *fearnóg, fearn,* features in many placenames, Ferns in Co. Wexford "the place of the alders", being an example. Alder is a common tree in wet soils and on river banks. Today, due to improvements in drying technology, its timber is quite valuable and is often called "Irish mahogany". In ancient times it was valued for shield making and an example in the National Museum has a diameter of one metre -this single piece came from an exceptionally large specimen and today no trees of such dimensions exist in Ireland. It was also prized for harp making. Alder was also used to make clogs and Wyse-Jackson (2014) records that alder clogs made in Enniscorthy, Co. Wexford, were worn by the workers in the National Botanic Gardens up to the 1950s. In the Irish laws it was a "commoner" and is found in the second of the four categories of native trees.

Glenfarne, *Gleann Fearna,* "valley of the alder", Co. Leitrim;
Farney, *Fearnaigh,* "alder-plain", a barony in Co. Monaghan;
Borrisnafearney, *Buiríos na Fearna*, "the borough of the alder", Co. Tipperary;
Ballyfarnon, *Béal Átha Fearnáin*, "the ford-mouth of alder", Co. Roscommon;
Anaverna, *Áth na bhFeárnaí*, "ford of the alders", Co. Louth;
Ferns, *Fearna,* "the alders or place of alders", Co. Wexford;
Farnaun, *Fearnán*, "place of alders";
Cappanavarnoge, *Ceapach na bhFearnóg* "tillage plot of the alders", Co. Clare;
Gortnavarnoge, *Gort na bhFearnóg*, "the field of the alders", Co. Tipperary.

Arbutus, **strawberry tree,** *caithne,* appears in several placenames even though it is only native to Glengarriff, Co. Cork, Killarney, Co. Kerry and Lough Gill, Co. Sligo. Arbutus fruits may be eaten, but are usually very sour. Wyse-Jackson (2014) states that they were eaten in the south west by poorer people. The only known examples of the tree in placenames are found in:

Arbutus Island, *Oileán na Caithne*, Co. Kerry, an island on the Iveragh Peninsula (parish of Dromod near Cahersiveen);
Ardcanny - *Ard Caithne,* "height of the arbutus" Co. Limerick, the name of a civil parish;
Smerwick (itself a Viking name), *Ard na Caithne*, "the height of the arbutus", Co. Kerry;
Isknagahiny, *Eisc na gCaithne,* "stream of the arbutus trees", near Waterville, Co. Kerry.

Ash, *fuinseog,* is one of the most versatile and widespread of Ireland's native species and the Brehon laws classified it as a "noble of the wood" indicating its importance to society at that time. It is represented in townland names in several Irish variants, *fuinse, fuinseann* and *fuinseog*. The latter, which is the most modern, is almost universally used while the others are now nearly forgotten. The Funshion River, *Abhainn na Fuinseann*, Co. Tipperary the ash-producing river, preserves one of the old forms. Also:

Barnafunshin, *Bearna na Fuinseann,* "the gap of the ash", Co. Clare;
Killanafinch, *Cill na Fuinseann,* "the church of the ash", Co. Tipperary;
Cornafunshin, *Corr na Fuinseann,* "the round of the ash", Co. Longford;
Derrynafinchin, *Doire na Fuinseann,* "oak wood of the ash", Co. Cork;
Cloonafunshin, *Cluain na Fuinseann,* "meadow of the ash", Co. Galway;
Funshin, *Fuinseann,* "place of ash", Co. Galway;
Funshinaugh, *Fuinseannach,* "place of ash", Co. Mayo;
Unshogagh, *Fuinseogach,* "place of ash trees", Co. Cavan;
Ashglen or Glennafunshoge, *Gleann na Fuinseoige,* "the glen of the ash", Co. Kilkenny;
Lisnafunshin, *Lios na Fuinseann*, "the ring-fort of the ash", Co. Kilkenny;
Lough Funshinagh, *Loch Fuinseann,* "lake of the ash", Co. Roscommon;

Tomnafunshoge, *Tuaim na Fuinseoige*, "the burial mound of the ash", Co. Wexford;
Corrinshigagh, *An Chorr Uinseogach,* "the round hill of ash trees", Co. Monaghan.

The ash is also found in a number of placenames of English language origin, some of which have been given modern Irish translations, such as Ashford, *Áth na Fuinseoige*, Co. Wicklow and Ashfield, *Gort na Fuinseoige* in Co.'s Dublin, Kilkenny, and Limerick.

Aspen, *crann creathach*, is a minor species and today the tree is little used. In early times the leaves were used as fodder. A large cauldron made of aspen with yew handles was found in a bog in Monaghan and is now in the National Museum of Ireland.
Crancragh, *An Crann Creathach,* "the aspen tree", Co. Offaly is the only placename containing this tree.

Bramble or **briar**, *dris,* is found in large number of placenames throughout the country. The following are some examples:
Drisheen, *An Drisín*, "place of brambles", Co. Cork;
Drishane, *Driseán*, "place of brambles", Co.'s Cork and Tipperary;
Monadrishane, *Maigh Dhriseáin*, "the plain of brambles", Co. Cork;
Fiddaunnadrishoge, *Feadán na Driseóige,* "the stream of the bramble", Co. Mayo;
Drisoge, *Driseog*, "place of brambles", Co. Carlow;
Drishog, *Driseog*, "place of brambles", Dublin, Leitrim, Roscommon;
Dressogagh*, Driseogach*, "place of brambles", Co. Armagh;
Cooldrishoge, *Cúil Driseoige,* "the corner of the bramble", Co. Waterford;
Ballynadrishoge, *Baile na nDriseog*, "townland of the brambles", Co. Wexford;
Cordressogagh, *An Chorr Dhriseogach*, "round hill of the brambles", Co. Cavan;
Gortnadrass, *Gort na Dreasa*, "the field of the bramble", Co. Sligo;
Kildress, *Cill Dreas*, "church of the brambles", Co. Tyrone;
Kiltrassy, *Cill Dreasa*, "church of the bramble", Co. Kilkenny.

Broom: reed, *giolcach*, this word is used differently in different parts of the country -in the north and west it refers to reeds, elsewhere it refers to broom:
Guilcagh, *An Ghiolcach,* "place of broom or reeds", Co. Waterford;
Guilkagh, *An Ghiolcach,* "place of broom or reeds", Co. Kilkenny;
Gilky Hill, *An Ghiolcaigh,* "place of broom or reeds", Co. Down;
Kilgilky, *An Choill Ghiolcaigh*, "the wood of reeds", Co. Cork and Knocknagilky, *Cnoc na Giolcaí,* "the hill of the broom", Co. Wicklow;
Ballinagilky, *Baile na Giolcaí,* "townland of the broom", Co. Carlow.

Birch, *beith,* a very common tree which was classified as a "commoner" in the tree list, has many placenames called after it. While the virtues of birch have been extolled in verse, the inferior quality of its timber makes it a tree of secondary importance.

Birch twigs were used as brooms before modern materials became available.

Ballybay, *Béal Átha Beithe,* “ford-mouth of the birch”, Co. Monaghan;

Glenbeigh, *Gleann Beithe*, “valley of the birch”, Co. Kerry;

Aghavea, *Achadh Bheithe,* “field of the birch”, Co. Fermanagh;

Anveyerg, *An Bheith Dhearg,* “the red birch”, Co. Monaghan;

Benagh, *Beitheánach,* “place of birch trees”, Co. Down;

Behy, *An Bheithigh,* “place of birch trees”, Co.’s Cavan, Donegal, Mayo, Roscommon and Sligo;

Beheenagh, *An Bheithíneach,* “place of birch trees”, Co. Kerry;

Bahana, *An Bheitheánach,* “place of birch trees”, Co.’s Carlow and Wicklow.

Blackthorn, d*raighean*. There are many townlands named after the Irish word for blackthorn *draighean*, and its derivatives, including:

Drinagh, *Draighneach,* “place of blackthorns”, Clare, Cork, Galway, Laois, Offaly and Wexford and Dreenagh, Co. Kerry;

Drinan, Co. Dublin, Drinaun, Co.’s Cork, Galway, Roscommon, and Dreenaan Co. Limerick all from *Draighneán,* “place of blackthorns”;

Keadydrinagh, *Céide Draighneach,* Co. Sligo, “Flat-topped hill of the blackthorns”;

Kildreenagh, *Cill Draighneach,* “church of the blackthorns”, Co. Carlow;

Meenadreen, *Mín an Draighin,* “mountain pasture of the blackthorn”, Co. Donegal;

Monadren, *Móin an Draighin,* “the bog of the blackthorn”, Co. Tipperary.

Cherry, *crann silíní,* (there are two separate species – “wild” and “bird”). Cherry tends to prefer to grow as a solitary tree and may not have been widespread in the landscape. Only one example of a townland named from the tree has been found:

Cahernashilleeny, *Cathair na Silíní,* “the stone fort of the cherries”, Co. Galway.

Cherry Orchard, *Gort na Silíní,* Cherrywood, *Coill na Silíní,* Co. Dublin are recent names of English origin which have been given Irish translations.

Crab-apple*, crann fia-úll,* ***apple tree*** *abhall,* an important tree species because of its fruit, is found in several townland names as in Aghowle, Co. Wicklow and Aghyowla, Co. Leitrim. The tree is found as a component in the word *abhallort*, earlier *abhallghort*, “orchard” which also occurs in townland names:

Theoil, *An Abhaill*, “the apple tree”, Co. Wexford;

Avalbane, Ab*haill Bhán*, “the white apple tree”, Co. Monaghan;

Oolagh, *Abhlach*, “place of apple trees” Co. Kerry;

Aghowle, *Achadh Abhall,* “field of the apple trees”, Co. Wicklow;

Aghyowla, *Achadh Abhla*, “field of the apple tree”, Co. Leitrim;

Clonoulty, *Cluain Abhla*, “meadow of the apple tree”, Co. Tipperary;

Dunowla, *Dún Abhla*, “fort of the apple tree”, Co. Sligo;

Cornahawla, *Corr na hAbhla*, "round hill of the apple tree", Co. Monaghan;
Gortnanoul, *Gort na nAbhall*, "field of the apple trees", Co. Cavan;
Portora, *Port Abhla*, "port or landing place of the apple tree", Co. Fermanagh;
Aldworth, *An tAbhallort*, "the orchard", Co. Cork;
Avaltygort, *An tAbhallghort*, "the orchard", Co. Donegal;
Orchard, *An tAbhallort Fiáin*, "the wild orchard", Co. Carlow.

Elder, (boor tree), *trom,* was a useful food source and was important for medicinal purposes in early Ireland and throughout Europe. It is found in many placenames including Trim, Co. Meath.

Trim, *Baile Átha Troim*, "the town of the ford of the elder", Co. Meath;
Annatrim, *Eanach Troim*, "marsh of the elder", Co. Offaly;
Cooltrim, *Cluain Troim*, "meadow of the elder", Co. Monaghan;
Listrim, *Lios Troim*, "ringfort of the elder", Co. Kerry;
Monatrim, *Muine Troim*, "thicket of the elder", Co. Waterford.

Elm, *leamh*, *leamhán*, was a very important tree in ancient Ireland, especially in the more fertile areas. Its disappearance may be due to clearance for agriculture or a disease. It is found in the Gaelic form in the names of many townlands. It is found in a number of early compound names such as Leamh-choill "elm wood":

Derrylavan, *Doire Leamhán*, "oak wood of the elms", Co. Monaghan;
Dromalivaun, *Drom an Leamháin,* "ridge of the elm", Co. Kerry;
Whitefort, *Ráth an Leamháin,* "ring-fort of the elm", Co. Tipperary;
Lislevane, *Lios Leamháin*, "ring-fort of the elm", Co. Cork;
Lavagh, *Leamhach*, "place of elms", Co.'s Cavan, Galway, Kilkenny, Laois, Leitrim, Offaly, Roscommon and Sligo;
Lavey, *Leamhaigh*, "place of elms", Co. Cavan;
Lucan, *Leamhcán*, "place of elms", Co. Dublin;
Laughil, *Leamhchoill,* "elm wood", Co.'s Galway and Longford;
Longfield, *Leamhchoill*, Co.'s Donegal, Derry, Leitrim and Monaghan;
Lorum, *Leamhdhroim*, "elm ridge", Co. Carlow.

Furze, *aiteann,* played a very important part in life in ancient Ireland and right up to the middle of the 20th century as fodder for farm animals. Its wood, because if its high calorific value, was very useful during the World Wars to keep baker's ovens going when there was a shortage of imported fuel. Many place-names carry a reference to furze, including:

Ardattin, *Ard Aitinn*, "height of the furze", Co. Carlow;
Coolattin, *Cúil Aitinn*, "corner of the furze", Co. Wicklow;
Ballinattin, *Baile an Aitinn*, Co.'s Tyrone and Waterford;

Ballynahatinna, *Baile na hAitinne*, "townland of the furze", Co. Galway and also Ballynahatten, *Baile na hAitinne*, "townland of the furze", Co.'s Down and Louth;
Knockanattin, *Cnoc an Aitinn*, "hill of the furze" Co. Tipperary;
Knocknahattin, *Cnoc na hAitinne*, Co. Meath;
Lyrattin, *Ladhar Aitinn*, "fork of the furze", Co. Waterford.

Hawthorn, *sceach,* was classified as a "commoner" in early Irish law. The wood is tough but there is no evidence that it was used extensively. The haws can be eaten but only when nothing else is available -hence the old adage "when all fruit fails, welcome haw". According to (Perrin et al. 2008), hawthorn is the most frequently occurring native tree today, but it may not be abundant. Several townlands are called after the hawthorn or white-thorn in the Irish derivative *sceach*. Hawthorn seems to have enjoyed some type of spiritual significance. It is found near holy wells and even today, in many places, ribbons and rags are tied to them. Religious objects are also attached to hawthorn as offerings. The presence of hawthorns saved many ring-forts from destruction because of the superstition of interfering with trees on these sites. All this would seem to be a remnant of pagan rituals.

Skeagh, *An Sceach*, "the hawthorn", Co.'s Cavan, Cork, Donegal, Dublin and Skagh, Co.'s Cork and Limerick;
Skahard, *An Sceach Ard*, "the high hawthorn", Co. Leitrim;
Ballinaskeagh, *Baile na Sceach*, "townland of the hawthorns", Co. Down;
Knocknaskagh, *Cnoc na Sceach*, "hill of the hawthorns", Co. Cork, also Knocknaskea, Co. Longford and Knocknaskeagh Co. Wexford;
Gortnaskehy, *Gort na Sceiche*, "field of the hawthorn", Co. Limerick;
Knockskemolin, *Cnoc Sceiche Moling*, "the hill of St. Moling's hawthorn", Co. Wexford;
Skehanagh, *An Sceachánach*, "place of hawthorns", Co.'s Galway, Laois, Limerick, Mayo, Tipperary.

Hazel, *coll,* is included in the "nobles of the wood" category. No doubt this is because of the importance of hazel nuts in the early Irish diet. Hazel was also important in the building of fences, enclosures and house-walls as the rods were pliable and fast growing (Kelly 1999). Several placenames derive from hazel including:

Gortahile, *Gort an Choill*, "the field of the hazel", Co. Laois, also Gortaquill, Co. Cavan;
Lisaquill, *Lios an Choill,* "the ring-fort of the hazel" Co.'s Longford and Monaghan, also Lissakyle, Co. Tipperary;
Garraun (Coyle), *Garrán Coill,* "grove of the hazel" Co. Galway, also Garrankyle, Co. Tipperary;
Barnacoyle, *Bearna Choill*, "gap of the hazel", Co. Wicklow;
Barnankile, *Bearna an Choill*, "the gap of the hazel", Co. Waterford;
Glenhull, *Gleann Choll*, "glen of hazels", Co. Tyrone;

Ardahill, *Ard an Choill*, "the height of the hazel" Co. Cork;
Callowhill, *Collchoill*, "hazel-wood", Co.'s Leitrim and Monaghan;
Drumcolliher, *Drom Collachair*, originally *Drom Collchoille* "ridge of the hazel-wood", Co. Limerick.

Collchoill, the official Irish form of Hazelhatch, Co. Kildare is a modern translation of the original English name.

Heather, *fraoch,* was important because of its value as fodder and bedding for animals. The best known placename containing the word is Inishfree Island, Co. Sligo, which was immortalised in Yeats's poem "Lake Isle of Inisfree". The word *fraoch* also means "heath" and it is found with this meaning in names such Freaghmore, *An Fraoch Mór* in Co. Westmeath and Freaghduff, *An Fraoch Dubh* in Co. Tipperary. *Fraochán*, "bilberry" is from the same root word in Irish, similarly there is Gortnavreaghaun, *Gort na bhFraochán* in Co. Clare, and Kylefreaghane, *Coill na bhFraochán* in Co. Tipperary.

In the following placenames the word fraoch refers to heather:
Inishfree, *Inis Fraoigh*, "island of heather", Co.'s Donegal and Sligo;
Gortfree, *Gort Fraoigh*, "field of the heather", Co.'s Mayo and Tipperary;
Monaree, *Móin an Fhraoigh*, "the bog of the heather", Co.'s Kerry and Tipperary;
Knockanree, *Cnoc an Fhraoigh*, "the hill of the heather", Co. Wicklow;
Ummerafree, *An tIomaire Fraoigh*, "the ridge of heather", Co. Monaghan;
Laherfree, *Láthair Fraoigh*, "site of the heather", Co. Kerry;
Freaghillan, *Fraochoileán*, "heather-island", Co. Mayo.

Holly*, cuileann,* is a "noble of the wood" which places it among the most valuable trees in the wood. One of the few evergreen native trees its foliage was used as fodder. It also had spiritual qualities which predated Christianity. *Cuileann* is found in many townlands names examples of which are

Cullen, *An Cuileann*, "the holly", Co. Cork;
Altachullion, *Alt an Chuilinn*, "glen of the holly", Co. Cavan;
Glencullen, *Gleann Chuilinn*, "valley of the holly", Co. Dublin and Glencullin, *Gleann Chuilinn*, Co.'s Mayo and Clare;
Moycullen, *Maigh Cuilinn*, "plain of the holly", Co. Galway;
Drumcullen, *Droim Cuilinn*, "ridge of the holly", Co.'s Antrim, Armagh and Offaly;
Garinish Island, *Oileán an Chuilinn*, Co. Cork;
Hollyhill, *Cnoc an Chuilinn*, "the hill of the holly", Co. Cork and Knockacullen Cork, *Knockacullion*, Co.'s Leitrim and Monaghan;
Cullenagh, *Cuileannach*, "place abounding in holly", Co.'s Clare, Cork, Galway, Laois, Limerick and Waterford;

Cullentragh, *An Chuileanntrach*, “place abounding with holly”, Co.’s Armagh, Cavan, Kilkenny, Longford, Leitrim and Mayo.

Honeysuckle, woodbine *féithleann, féithleog* and in the south of the country, *táithfhéithleann*. It remains a very common plant which is recorded today in the Inventory of Native Woodlands in 84.5% of sites. It gives its name to Aghnaveiloge, *Achadh na bhFéithleog,* “field of the honeysuckles” in Co. Longford and possibly to Lisnavaghrog, *Lios na bhFeathróg,* “ringfort of the honeysuckles” in Co. Down.

Ivy, *eidheann, eidhneán*. According to the Inventory of Native Woodlands, ivy was found on 96.6% of sites. The following placenames are examples:

Inagh, *Eidhneach*, “place of ivy”, Co.’s Clare and Mayo;

Inane, *Eidhneán*, “place of ivy”, Co.’s Cork and Tipperary, also Einaun Island, Co. Kerry and Inan, Co. Meath;

Gleninagh, *Gleann Eidhneach*, “valley of the ivy”, Co. Clare and Galway;

Eany Water, *An Eidhnigh*, “the ivied river”, Co. Donegal, also Hind River, An Eidhneach, Co. Roscommon;

Leckenagh, *Leac Eidhneach*, “the ivied flagstone”, Co. Donegal;

Corragina, *Carraig Eidhneach*, “ivy rock”, Co. Waterford.

Juniper, has at least three different Irish names, *biora leacra, iúr creige* and *aiteal* which is the term most commonly used today. However, the other Irish terms describe the species better. *Iúr creige* translates as rock yew and *biora leacra*, spears or spines of the rock. The possible reason that juniper is scarce as a placename, apart from its limited range on limestone soils, is that the Irish name *aiteal* is very similar to *aiteann*, the Irish for furze/whins. Juniper was assigned to the lower divisions of the wood. There are no known Irish placenames containing the tree name. Juniper Island in Co.’s Donegal, Clare and Upper Lake Killarney, Co. Kerry are recently coined English names. The original Irish names of these islands are not known.

Oak, *dair.* Oak was a very widespread and important tree in ancient Ireland, hence the many townlands named after it and also two Irish counties, Derry and Kildare, derived from the Gaelic word *dair.* Oak was prized for its acorns, wood and bark. The bark had many uses including the tanning of leather and as vessels for keeping food when pottery vessels were not available. Acorns were used to feed pigs and according to Kelly (1999), a single oak can provide enough acorns to fatten one pig in a single year. There is no evidence that the acorns were used to make flour as in other cultures. *Dair* and its derivatives are found in a large number of placenames, the following are some examples:

Kildare, *Cill Dara*, "church of the oak" Co. Kildare and also Kildarra, Co. Meath;

Ballysadare (Ballisodare), *Baile Easa Dara*, "the town of the waterfall of the oak", Co. Sligo;

Adare, *Áth dara*, "ford of the oak", Co. Limerick;

Lackendarragh, *Leacain Darach*, "hillside of the oaks", Co.'s Cork, Limerick and Wexford and *Leacain Dara* Co. Tipperary;

Durrow, *Darú*, "oak-plain" (dair + magh "plain"), Co.'s Laois, Offaly, Galway, Waterford and Westmeath, also *Drough Darúch*, "oak-plain", Co. Cork;

Valentia Island, *Dairbhre*, "place of oaks", Co. Kerry and also Darrary in Co. Cork, Darrery in Co. Limerick, and Darver in Co. Louth and Kildorrery, *Cill Dairbhre*, Co. Cork

Derry, *Doire*, "oak-wood", Co.'s Derry, Cork, Galway, Monaghan, Sligo and Tipperary;

Derrylahan, *Doire Leathan*, "broad oakwood", Co.'s Cavan, Cork, Donegal, Galway, Laois, and Offaly;

Derrynane, *Doire Fhionáin*, "oakwood of St. Fionán", Co. Kerry;

Derrynaseera, *Doire na Saortha*, "oakwood of the craftsmen", Co. Laois and also Dernaseer, *Doi re na Saor, Co. Tyrone;*

Derreen, *An Doirín*, "small oakwood", Co.'s Clare, Kilkenny, Kerry, Galway, Laois and Leitrim;

Ballaghaderreen, *Bealach an Doirín*, "the road of the small oakwood" Co. Roscommon.

Two other words signifying "oak" are found in a small number of placenames. The first, *rail*, occurs in the names Drumralla, *Droim Ralach*, "ridge of oaks", Co. Fermanagh, Cloonreleagh, Co. Galway, Cloonreliagh, Co. Roscommon, *Cluain Roilíoch*, "meadow of oaks" and *Raileach*, "place of oak", Co. Derry. The second, *omna*, is found in Portumna, *Port Omna*, "landing place of the oak", Co. Galway and Drumumna, *Drom Omna*, "ridge of the oak", Co. Clare.

Rowan/mountain ash, *caorthann, cárthann*, resides in the second category of trees "Commoners of the Wood". It was important for its berries and it also has a very significant place in folklore. It is found in many placenames such as Carhan near Cahersiveen, birthplace of Daniel O'Connell.

Drumkeeran, *Droim Caorthainn*, "ridge of the rowan", Co.'s Antrim, Cavan, Fermanagh, and Leitrim;

Corkeeran, *Corr Chaorthainn*, "round hill of the rowan", Co. Monaghan;

Ballykeeran, *Béal Átha Chaorthainn*, "ford-mouth of the rowan", Co. Galway;

Altakeeran, *Allt an Chaorthainn*, "glen of the rowan", Co. Leitrim;

Ardkeeran, *Ard Caorthainn*, "the height of the rowan", Co. Sligo;

Ballaghkeeran, *Bealach Caorthainn*, "road of the rowan", Co. Westmeath;

Aghakeeran, *Achadh an Chaorthainn*, "field of the rowan", Co. Longford;
Keernaun, *Caorthannán*, "place of rowans", Co. Galway and Castlehill, *Caorthannán*, Co. Mayo.

Scots pine, *giús,* is very rarely found in townland names, possibly indicting that it was not abundant from early Christian times. Pine is one of the most useful timbers in the world and no doubt early settlers were aware of its attributes and proceeded to denude whole areas of the species. Pine, unlike other native tree species, does not coppice or regenerate after cutting, hence its demise. Pine was also prized for its resin which was used to make boats and vessels watertight. There is also the possibility that where it does occur it is unclear whether it was called after a living tree or bog-deal. Monagoush near Ardmore, Co. Waterford indicates a bog "móin" and the bog may have supplied bog-deal and the first part of Meenaguse, near Inver, Co. Donegal, refers to a mountain meadow.
Meenaguse *Mín an Ghiúis*, "mountain pasture of the pine", Co. Donegal;
Monagouse, *Móin an Ghiumhais*, "the bog of the pine", Co. Waterford;
Lough Aguse, *Loch an Ghiúis*, "lake of the pine", Co. Fermanagh;
Cappayuse, *Ceapaigh Ghiúsa*, "tillage plot of the pine", Co Roscommon.

This is not a large representation for such an important tree.

Willow, sally, *saileach* despite its important role in ancient Irish life, the willow was merely a "Commoner of the wood" under Brehon law. Apart from basket making, willow was used to make a multiplicity of objects including scallops for thatching. It is probable that its ability to regenerate quickly made it the lesser species category with a lesser fine. Willow species have long been recognised as forming the basis of the pain killing drug, aspirin.
Clonsilla, *Cluain Saileach*, "meadow of the willow", Co. Dublin and Cloonsillagh, Co. Kerry;
Corsillagh, *Corr Shaileach*, "round hill of the willow", Co. Wicklow;
Drumsillagh, *Druim Saileach*, "ridge of the willow", Co.'s Cavan, Fermanagh, Leitrim, Meath and Roscommon;
Woodview (Mullanasilla), *Mullach na Saileach,* "summit of the willow", Co. Armagh and Mulnasillagh, Co. Leitrim;
Gortnasillagh, *Gort an Saileach*, "field of the willow", Co.'s Donegal, Galway, Leitrim and Mayo;
Ballinasilloge, *Baile na Saileog*, "townland of the willows", Co.'s Wicklow and Wexford;
Parknasilla, *Páirc na Saileach*, "the field of the willows", Co. Kerry;
Silloge, *Saileog*, "place of willows", Co. Dublin;
Seltan, *Sailtean*, "place of willows", Co. Leitrim.

Yew, *eo* (early), *iúr,* appears to have been a very important tree in ancient Ireland because after oak, it is the most common species in Irish placenames. The two words for yew are found in several well-known placenames including Mayo, Youghal and Newry:

Mayo, *Maigh Eo*, "plain of the yews", Co. Mayo also Co.'s Laois and Leitrim;
Glanoe, *Gleann Eo*, "glen of the yews", Co. Kerry;
Drimmo, *Droim Eo*, "ridge of the yews", Co. Laois;
Aghadoe, *Achadh Deo*, "field of two yews", Killarney, Co. Kerry;
Youghal, *Eochaill*, "yew-wood", Co.'s Cork and Tipperary;
Ahoghill, *Achadh Eochaille*, "field of the yew-wood", Co. Antrim;
Newry, *An tIúr*, "the yew", Co. Down, also Nuremore "*An tIúr Mór*", Co. Monaghan;
Knockanure, *Cnoc an Iúir*, "hill of the yew", Co.'s Cork, Kerry, Monaghan and Tipperary;
Loughanure, *Loch an Iúir*, "lake of the yew", Co. Donegal;
Uragh, *An Iúrach*, "place of yews", Co.'s Cavan and Kerry, also Newrath, Co.'s Louth and Wicklow.

Long, long ago in the woods of Gort na móna…

Percy French

Collective names for woods and trees

Bile is a name given to a venerated tree or a large ancient tree, possibly survived from Celtic times. Today they would be called heritage trees. Examples are:

Bellia, *Bile*, "the ancient tree", Co. Clare;
Billymore, *An Bile Mór*, "the big ancient tree", Billy, Co. Antrim;
Movilla, *Maigh Bhile*, "plain of the ancient tree", Co. Down. It is also the original name of Moville Parish, Co. Donegal, but not of the town of Moville;
Dunbell, *Dún Bile*, "ringfort of the ancient tree", Co. Kilkenny;
Rathvilly, *Ráth Bhile*, "ring-fort of the ancient tree", Co. Carlow;
Knockavilla, *Cnoc an Bhile*, "hill of the ancient tree", Co.'s Galway, Mayo, Tipperary and Wexford;
Toberavilla, *Tobar an Bhile*, "the well of the ancient tree", Co. Waterford.

Craobh, branch, a tree.

Creeve, *An Chraobh*, "the tree", Co.'s Antrim, Longford, Monaghan, Roscommon, also Stewartstown, An Chraobh, Co. Tyrone;
Cremartin, *Craobh Mhártain*, "the tree of Mártan", Co. Monaghan, and also Crowmartin, Co. Louth;
Lough Crew, *Loch Craobh*, "lake of the trees", Co. Meath;
Meenacreeva, *Mín na Craoibhe*, "mountain pasture of the tree", Co. Donegal;

Cruagh, *An Chraobhach*, "place of trees", Co. Dublin;

Creevy, *An Chraobhaigh*, "place of trees", Co.'s Donegal, Down, Leitrim and Monaghan.

Mothar "a thicket".

Moher, *An Mothar*, "the thicket", Co.'s Cavan, Kerry, Cork, Galway, Laois, Leitrim, Tipperary;

Cliffs of Moher, *Aillte an Mhothair*, Co. Clare;

Mohernagh, *Motharnach*, "place of thickets", Co. Limerick.

Gaorthadh, a woodland along a river, is confined to Munster:

Gearha, *A*n Gaorthadh, "the wooded valley", Co. Kerry also Gearagh, Co. Cork, Geeragh, Co. Limerick, and Gairha, Co. Waterford;

Garrynapeaka, *Gaorthadh na Péice*, "wooded valley of the peak", Co. Cork;

Ballingeary (Bealanageary), *Béal Átha an Ghaorthaidh*, "ford mouth of the wooded valley", Co. Cork.

Garrán a grove or shrubbery is found frequently in Munster and Connaught as Garran, Garrane and Garraun. It is also found in Leinster, but not often, except in Kilkenny. It occurs several times in Monaghan, but does not appear elsewhere in Ulster.

Garranamanagh, *Garrán na Mana*ch, "the grove of the monks", Co. Kilkenny;

Garraundarragh, *An Garrán Darach*, "the oak grove", Co. Kerry;

Garranbawn, *Garrán bán*, "white grove", Co. Kerry;

Bellanagarraun, *Béal Átha na nGarrán*, "the ford mouth of the groves".

Muine, thicket or shrubbery, found in the name Muineachán, Co. Monaghan. It is often anglicised to money, as in Moneymore, Co. Derry, and Moneystown, Co. Wicklow:

Money, *An Muine,* "the thicket", Co.'s Cavan, Mayo, Monaghan, and Offaly, also Moneystown, Co. Wicklow and Munnia, Co. Tipperary;

Moneymore, *Muine Mór*, "big thicket", Co.'s Derry and Donegal;

Moneygall, *Muine Gall*, "thicket of the foreigners", Co. Offaly ;

Monaghan, *Muineachán*, "place of thickets", Co. Monaghan.

Scairt, a thicket, confined mainly to Munster and Co. Kilkenny.

Scart, *An Scairt*,"the thicket", Co.'s Cork, Kerry, Kilkenny;

Ballinascarty, *Béal na Scairte*, "mouth of the thicket" Co. Cork;

Scartaglin, *Scairteach an Ghlinne*, "place of thickets of the glen" Co. Kerry.

Crann, a tree.

Cranmore, *An Crann Mór,* "the big tree", Co. Mayo;

Ballynagrann, *Baile na gCrann*, "the town of the trees", Co. Wicklow;

Crancam, *An Crann Cam*, "crooked wood", Co.'s Longford and Roscommon;

Crannagh, *Crannach*, “place of trees”, Co. Kilkenny, also Cranna, Co. Tipperary and Cranagh, Co. Wicklow, also Cranny, *An Chrannaigh* in Co.’s Clare, Donegal and Tyrone.

Wood, *ros, fiodh,* and *coill* are three Irish names for woods which feature in their Anglicised form as *ros, fee, kil, kyle* which can be confused with *cill,* kill meaning church. Joyce estimates that about a fifth of the kills are wood. *Coill* is by far the most common word for a wood which occurs in well over a thousand names throughout the country.

Kilnamanagh, *Coill na Manach* “wood of the monks”, Co.’s Tipperary and Wicklow;
Kylemore, *An Choill Mhór*, “the big wood”, Co.’s Galway, Kilkenny, with variants Kilmore and Cuilmore found throughout the country;
Barnacullia, *Barr na Coille*, “top of the wood”, Co. Dublin. This wood still exists;
Kiltyclogher, *Coillte Clochair*, “woods of the stony place”, Co.’s Leitrim, and Tyrone.

The word *fiodh* occurs in a number of comparatively early names.
Fiddown, *Fiodh Dúin*, “wood of the fort”, Co. Kilkenny;
Feighcullen, *Fiodh Cuileann*, “wood of the holly trees”, Co. Kildare;
Fethard, *Fiodh Ard*, “high wood”, Co.’s Tipperary and Wexford;
Fews, *Na Feá*, “the woods”, Co. Armagh, also Fews, *Na Feadha*, Co. Waterford;

The third word, *ros*, means a headland in some parts of the country but refers to a wood in the following:
Roscommon, *Ros Comáin*, “the wood of (Saint) Comán”, Co. Roscommon;
New Ross, *Ros Mhic Threóin*, the wood of the Mac Treóin” Co. Wexford;
Roscarbery, *Ros Ó gCairbre*, “the wood of the descendents of Cairbre”; Co. Cork;
Roscrea, *Ros Cré*, “wood of the clay”, Co.’s Galway, Offaly and Tipperary.

On Carrig Donn the heath is brown,
The clouds are dark o’re Ard na Laoi
And many a stream is rushing down
To swell the angry Abhna Buí.

Denny Lane

The uses of wood

Bark was very important for tanning leather. Oak bark was the sought after as it has a high tannin content. There are several words for bark in Irish, *coirt, snamh* and *rúsc* but only the latter appears to be found in placenames.

It is found in the Irish name of Carrick-on-Shannon, *Cora Droma Rúisc*, “the weir of the ridge of the bark” Co. Leitrim. Other examples are Drumroosk, *Droim Rúisc*, “ridge of the bark”, Co.’s Leitrim and Monaghan, and Clonroosk, *Cluain Rúisc*, “meadow of the bark”, Co. Offaly.

Berries, *caor,* is a generic term for all native berries which were an important food source. It is common in placenames including:

Glannagear, *Gleann na gCaor*, "the glen of the berries", Co. Cork, also Glennageer, Co. Clare. Croaghnageer, *Cruach na gCaor*, "the mountain stack of the berries", Co. Donegal;

Monagear, *Móin na gCaor*, "the bog of the berries", Co. Wexford.

The official Irish version of Vinegar Hill, also in Wexford, is *Cnoc Fhiodh na gCaor*, "the hill of the wood of the berries", but the original form of the name is unknown.

Blackberry, *sméar* (*dubh*), the fruit of the bramble hence the large number of places named after the bramble. These berries provided sustenance in the autumn before the lean times of winter. Examples are:

Cappanasmear, *Ceapach na Sméar*, "tillage plot of the blackberries", Co. Tipperary;

Coolnasmear, *Cúil na Sméar*, "the nook of the blackberries", Co. Waterford;

Creenasmear, *Críoch na Sméar*, "the boundary of the blackberries", Co. Donegal;

Smear, *Sméar*, probably meaning "place of blackberries", Co. Longford;

Smearlagh River, which flows into the River Feale near Listowel, Co. Kerry, derives from the Irish, *An Sméarlach*, probably meaning "the river abounding in blackberries".

Firewood, *connadh,* was very important in ancient times for cooking and providing heat, just as it is today in many developing countries. There are many places deriving from this word throughout the country.

Pollahoney, *Poll an Chonnaidh*, "the hole of the firewood", Co. Wicklow;

Kilconny, *Coill Chonnaidh*, "the wood of the firewood", Co. Cavan;

Clonconny, *Cluain Connaidh*, "meadow of the firewood", Co. Kilkenny and Clooncunny in Co.'s Roscommon and Sligo, Clooncunnig in Co. Cork.

Nut, *cnó*, a very important food source, nuts could be preserved over the winter months. The word occurs in the following placenames:

Tullynagrow, *Tulaigh na gCnó*, "the hillock of the nuts", Co. Monaghan;

Cornagrow, *Corr na gCnó*, "the round hill of the nuts", Co. Cavan;

Ardnagno, *Ard na gCnó,* "the height of the nuts", Co. Galway;

Coolknoohill, *Cúil Chnóchoille*, "nook of the nut-wood", Co. Kerry.

Stake*, smután,* denotes a log or a stump of a tree and is found in:

Ballysmuttan, *Buaile na Smután*, "milking place of the tree stumps", Co. Wicklow;

Parknasmuttaun, *Páirc na Smután*, "the field of the stumps", Co. Kerry;

Lough Nasmuttan, *Loch na Smután*, "the lake of the stumps", Co. Donegal.

Sloe, *airne,* the fruit of the blackthorn, a useful food source. Stones from the sloe have been found at ancient cooking sites. The word occurs in several placenames, the best-known being Killarney, Co. Kerry.

Killarney, *Cill Airne*, "the church of the sloe", Co. Kerry;
Coolanarney, *Cúil an Airne*, "nook of the sloe", Co.'s Cork, Offaly;
Bollarney, *Buaile Airne*, "milking place of the sloe", Co. Wicklow.

Timber*, adhmad,* there appears to be only one townland associated with timber, namely Clashanimud, *Clais an Adhmaid*, "the trench of the timber", Co. Cork. This is not surprising as wood was probably used in the round because the equipment to square felled trees was developed at a point much later.

Withered wood, *críon,* an area covered with withered brambles or the withering remains of a wood, possibly a clearfelled area. It is found in the names, Creenkill, *Críonchoill*, "withered wood", Co.'s Armagh and Kilkenny, also Crinkill, *Críonchoill*, Co.'s Monaghan and Offaly. Creenary, *Críonaire*, "withered oak wood", Co. Donegal; Creenagh, An Críonach, "withered trees", Co. Leitrim.

Murneen, Curneen and Coillte Bó,
The three finest townlands in Co. Mayo.

Anon.

What of the future?

Much research on the origins of townland names has been carried out by very eminent scholars and the current interest and enthusiasm in genealogy will provide a renewed focus for their continual use. These townlands are now well documented and there is every possibility that they will survive in spite of Eircodes and other postcodes.

Foresters have played their part in ensuring that townlands names survived by signposting them at all recreational sites, Forest Parks and the People's Millennium Forests Project. Let us hope that this practice continues into the future and that a very important piece of our heritage continues to be safeguarded.

In the past townlands were named when trees and woods existed on the site. Today, we find new housing developments with the names of trees, Elmhurst, Oaklands, and Pinewood and there is not a tree in sight or if there is, it's more than likely a tree not associated with the name of the development. This attempt at gentrification does nothing to maintain and protect our trees or placenames heritage.

How about the following address in Celbridge, Co. Kildare: Willow Rise, Primrose Gate, Hazelhatch Road; not one of the aforementioned flora in sight!

You'll see the high Rocky Mountains on the west coast of Clare.
The towns of Kilrush and Kilkee can be seen.
From the high rocky slopes of the cliffs of Dooneen.

Jack Mc Aullife

References

Bunachar Logainmneacha na hÉireann, Placenames Database of Ireland. Available at www.logainm.ie [Accessed November 2016].

Burell, T. 2006. *The Anglicised Words of Irish Placemanes*. Nonsuch Publishing, Dublin.

Cross, J.R. 2012. *Irelands Woodland Heritage*. Department of Arts, Heritage and the Gaeltacht.

Cross, J.R. 2012. National Survey of Native Woodlands: a brief summary. *Irish Forestry* 69: 73–95.

Dinneen, P.S. 1927. *Foclóir Gaedhilge agus Béarla*. Irish Texts Society. Dublin.

Feehan, J. 2003. *Farming in Ireland. History, Heritage and Environment*. UCD, Dublin.

Irish Townlands. No date. Available at www.townlands.ie [Accessed November 2016].

Joyce, P.W. 1910. *Irish Names of places*. Reprint 1995 in 3 Vols. Éamon de Búrca. Dublin.

Joyce, P.W. 1923 *Irish Local Names Explained*. Reprinted 1996. Roberts, Dublin.

Joyce, P.W. 1968. *Irish Local Names Explained*. Fred Hanna Ltd., Dublin.

Joyce, P.W. 1984. *Irish Placenames*. Appletree Press. Belfast reprint of *Irish Local Names Explained*. (Fred Hanna, Dublin 1870.)

Kelly, F. 1998. *Early Irish Farming*. Dublin Institute for Advanced Studies.

Kelly, F. 1999. Trees in early Ireland. *Irish Forestry* 56: 39–57.

Lucas, A.T. 1963. The sacred trees of Ireland. *Journal of the Cork Historical and Archaeological Society* 68 (207 and 208): 16–54.

Mac Coitir, N. 2003. *Irish Trees: Myths, Legends and Folklore*. Collins Press, Cork.

Mac Coitir, N. 2006. *Irish Wild Plants: Myths, Legends and Folklore*. Collins Press, Cork.

Mac Giolla Easpaig, D. 2016. Personal Communication.

Mc Cracken, E. 1971. *The Irish Woods since Tudor Times*. David and Charles. Devon.

Nelson, E.C. and Walsh, W.F. 1993. *Trees of Ireland*. Lilliput Press, Dublin.

Ó hÓgáin, D. 2003. Trees in Irish lore. *Irish Forestry* 60: 45–60.

Ó Maolfabhail, A. (Ed.) 1992. *The Placenames of Ireland in the Third Millennium*. An Coimisiún Logainmneacha. Dublin.

Perrin, P., Martin, J., Barron, S., O'Neill, F., McNutt, K. and Delaney, A. 2008. *National Survey of Native Woodlands*. National Parks and Wildlife Service. Dublin.

Price, L. 2006. *The Placenames of County Wicklow*. Wicklow 400th Special Commemorative Edition. Reprint of 1945–1967 (seven volumes). Dublin Institute for Advanced Studies.

Room, A. 2009. *A Dictionary of Irish Placenames*. Appletree Press. Belfast.

Uí Chonchubhaair, M. 1998. *Flóra Chorca Dhuibhne*. Oidhreacht Chorca Dhuibhne. Ciarraí.

Uí Chonchubhaair, M. 2016. Personal Communication.

Wyse Jackson, P. 2014. *Irelands Generous Nature –The Past and Present uses of Wild Plants in Ireland*. Missouri Botanic Gardens Press.

Table 1: *List of trees native to Ireland.*

Scientific name	English name	Irish name	Notes
Alnus glutinosa (L.) Gaertn.	Alder	*fearnóg*	
Arbutus unedo L.	Arbutus	*caithne*	strawberry tree
Betula pendula Roth	Birch silver	*beith gheal*	
Betula pubescens Ehrh.	Birch downy	*beith chlúmhach*	
Calluna vulgaris (L.) Hull	Heather	*fraoch coiteann*	common heather
Cornus sanguinea L.	Dog wood	*conbhaiscne*	
Corylus avellana L.	Hazel	*coll*	
Crataegus monogyna Jacq.	Hawthorn	*sceach gheal*	whitethorn
Cytisus scoparius (L.) Link	Broom	*giolcach shléibhe*	
Erica spp.	Heather	*fraoch*	ling
Euonymus europaeus L.	Spindle	*feoras*	
Frangula alnus Mill.	Alder buckthorn	*draighean fearna*	
Fraxinus excelsior L.	Ash	*fuinseog*	
Hedera helix L.	Ivy	*eidhneán*	
Ilex aquifolium L.	Holly	*cuileann*	
Juniperus communis L.	Juniper	*aiteal*	biorra leachra, iubhar creige are other Irish names
Ligustrum vulgare L.	Privet	*prímhéad*	pribhéad
Lonicera periclymenum L.	Honeysuckle	*táthfhéithleann*	woodbine, Irish vine
Malus sylvestris (L.) Mill.	Crab apple	*crann fia - úll*	
Pinus sylvestris L.	Scots pine	*giúis*	péine Albanach
Populus tremula L.	Aspen	*crann creathach*	
Prunus avium L.	Cherry wild	*crann silín fiáin*	gean
Prunus padus L.	Cherry bird	*donnroisc*	
Prunus spinosa L.	Blackthorn	*draighean*	sloe
Quercus petraea (Matt.) Liebl.	Oak sessile	*dair ghaelach*	
Quercus robur L.	Oak pedunculate	*diar ghallda*	
Rhamnus cathartica L.	Common buckthorn	*paide bréan*	purging
Rosa canina L.	Dog rose	*feirdhris*	cronós, hip
Rubus fructicosus L., agg.	Bramble	*dris*	briar or blackberry
Salix spp.	Willow	*saileach*	sally
Sambucus nigra L.	Elder	*trom*	boor tree
Sorbus aucuparia L.	Rowan	*caorthann*	mountain ash, quicken
Sorbus spp.	Whitebeam	*fionncholl*	bíoma bán
Taxus baccata L.	Yew	*iúr*	
Ulex europeaus L.	Furze European	*aiteann gallda*	whin
Ulex gallii Planch.	Furze Irish	*aiteann gaelach*	mountain furze/whin
Ulmus glabra Huds.	Elm	*leamhán*	Irish or Wych elm
Viburnum opulus L.	Guelder rose	*caor chon*	

Ecosystem Services
Coillte's progress in the provision of public goods across its estate

Eugene Griffin[a*]

Abstract
This paper gives the background to the formation of Coillte Teoranta, the Irish Forestry Board, in 1989, and reviews its progress in the areas of recreation, nature conservation, biodiversity and landscape design. The findings of a study on the economic value of trails and forest recreation in Republic of Ireland are discussed, as is the current funding that supports the provision of recreation. The paper looks at how LIFE projects can play an invaluable role in supporting nature conservation. The results of a recent study on the valuation of the public goods provided by Coillte relating to landscape, habitats and species, and cultural heritage are presented.

Keywords: *Coillte, recreation, funding, nature conservation, biodiversity, landscape, valuation, LIFE.*

Introduction

Coillte Teoranta, the Irish Forestry Board, was formed at the beginning of 1989 with the mandate to operate as a commercial semi-state organisation. For all of its previous history, the forest estate was directly managed by a succession of Government Departments and during the 1980's was estimated to be in receipt of annual government subvention in excess of 30 million Irish punts (Anon, 1985). Following Coillte's establishment no further government funding was received. Coillte undertook a considerable amount of land acquisition and afforestation in the 1990's, but following an EU ruling that it was not entitled to afforestation premium payments, very little further acquisition occurred subsequently.

Coillte today has an estate of 443,000 ha of which 390,000 ha is under forest and has developed into a more broadly based company operating in forestry and in related businesses, such as renewable energy and in the manufacture of wood panel products.

Coillte's forests have dual international certification in terms of being responsibly and sustainably managed The adoption of sustainable management has brought with it a much sharper focus on the management of biodiversity in terms of habitats and species, landscape design and management including size of felling coupes, and stakeholder consultation and involvement.

Ecosystem services include the full range of goods and services that are delivered by the forest and include timber, water, forage, soil protection, recreation, nature

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conservation, biodiversity, landscape and cultural heritage. Timber is obviously an ecosystem service that can be traded. However, the services that are not tradable in the normal market are known as public goods and are a subset of ecosystem services, and include nature conservation, biodiversity enhancement, landscape management, protection of cultural heritage and provision of recreation.

Recreation

When Coillte was established it inherited most of the amenity areas/sites that were previously with the Forest and Wildlife Service, apart from the John F. Kennedy Park (Arboretum). While a few of those sites were closed, most remained open and continued to be maintained and or developed, and funded by Coillte without receiving any funding from Government. Coillte continued with the "Open Forest Policy" allowing unlimited pedestrian access to its entire estate. In 2005 Coillte published its first recreation policy *Healthy Forests, Healthy Nation*, in order to formalise a position on the provision of recreation in the light of changing public expectations and operating environments. Furthermore, Coillte in conjunction with the Irish Sports Council in 2005, commissioned Fitzpatrick Associates, Economic Consultants, to undertake a study on the economic value of trails and recreation in the Republic of Ireland. The research involved extensive primary and innovative research work, through both postal and on-site surveys. A questionnaire was sent to 3,000 households in Ireland, while some 640 trail and forest users were interviewed on-site at 15 locations throughout the country. The findings from this research were supplemented by a review of existing literature, consisting of three international comparative studies, and consultation with key stakeholders. This was the most significant report of its kind ever completed in Ireland. The main findings of the report were as follows:

- the total number of trail visits was estimated to be 17.5 million annually;
- the non-market value of forest recreation was €97 million per annum;
- visitors valued their visit at €5.40, using the willingness to pay and the costless choice models;
- economic activity generated by domestic forest visitors was estimated at €268 million annually;
- economic activity generated by overseas walking and cycling tourism in forests was estimated at €138 million annually.

It was determined from the three international comparative studies, that the governments in those countries were funding the development of trails and outdoor recreational facilities in a very significant way:

- New Zealand government was providing 60 million dollars annually, and
- the Scottish and Finnish governments were providing €25 million annually to their state owned forest companies.

The literature indicated that in nearly all countries, people using forest recreational facilities are not charged *per se*, and that the facilities are valued for the economic activity accruing from spending in the local areas, and also by attracting in and spending of foreign tourists. The report stated that Coillte's lands are well positioned to facilitate investment in Ireland's trail network, that Coillte's forests offer significant opportunities for the provision of a broad range of alternative recreational facilities including off-road cycling trails, horse riding trails and mountain biking, and that Coillte could also contribute to the development of a much needed national cycling trail network. Since the publication of this report there has been a greater awareness of Coillte's ongoing commitment and funding of recreation and also its great capability for improving existing recreational facilities, developing new ones and thereby significantly improving the recreational offering to both local residents and overseas tourists alike. Coillte owns and manages more than 50% of the entire national waymarked trail network and contributes very substantially to increased participation in outdoor recreation through management of more than 600 walking and cycling trails nationally. To leverage this public recreation offering, partnerships have been developed with government departments, agencies and local authorities to create funding streams to defray the costs of running this substantial infrastructural network.

Thus since 2008, funding has been received from the Sports Council for certain staff to work exclusively in trail management and development and recreation work across the estate. Since 2010, funding has been received annually from the government to fund recreation on the Coillte estate, which significantly increased in 2015. However, this funding varies from year to year making it difficult to plan and budget over the medium to long term timeframe of between five to ten years.

An important issue to note is that this funding is significantly below the overall costs of maintaining this recreational infrastructure. Coillte will seek, in partnership with other state agencies, additional funds to defray these ongoing costs.

Much progress has been made in recreation in recent years. In 2007, a new *Coillte Outdoors* website was launched where over 150 recreation sites are listed and where one can find full details of trails and facilities and download any required maps (www.coillteoutdoors.ie). Also in 2007, a newly refurbished Lough Key Forest and Activity Park was opened, which was the first recreational joint venture between Coillte and a local authority, Roscommon County Council, with major capital funding from Fáilte Ireland. Visitor numbers to the park have significantly increased since then and are currently greater than 72,000 annually. Over the last 6 years, a total of 142 km of mountain bike trails have been developed at four different sites throughout the country, the longest being 91 km in length. Coillte was instrumental in setting up the Dublin Mountains Partnership in 2008 with the local authorities in Dublin and a Coillte staff member has been seconded to work full time with the Partnership. One of the flagship projects of the Partnership was the long distance trail, the Dublin Mountains Way that crosses the Dublin Mountains for a distance of 42 kilometres.

In 2013, Coillte in partnership with Cavan County Council, commenced the development of an interpretive centre and new trail facilities at the Cavan Burren Park which is part of the Marble Arch Caves Global Geopark, which covers parts of Cavan and Fermanagh. The development, a cross-border initiative, was valued at over €900,000 and was financed by the European Union's INTERREG IVA Programme. The 124 hectares of the Burren Forest has an exceptional geological heritage along with a range of national monuments, ancient habitation sites and field systems that survive from prehistoric times. The Burren property was all afforested in the mid 1950's and this has been a very significant factor in the protection and preservation of the archaeological and geological features of the site. These new facilities were completed and opened in May 2014. In October 2014, this project won the RDS/Forest Service Community Award and in January 2015 it won the Heritage Section of the Local Authority Management Awards.

Biodiversity and nature conservation

Coillte has designated at least 15% of its estate to be managed for non-commercial purposes with biodiversity being the primary management objective, and that these areas would be identified on maps and protected from harvesting and other high impact forest operations. Between 2001 and 2005, Coillte employed a number of contract ecologists, who following consultation with the local forest managers, surveyed the entire forest estate and determined the most valuable areas for biodiversity management (O'Sullivan 2004). Each forest management unit area has a detailed site description and management plan, and is now a separate layer on the company's geographical information system (GIS). This system allows staff to readily identify "designated biodiversity areas" and thus ensure their protection from forest operations where required. Over the years other potential biodiversity sites have been identified and recorded and this currently amounts to an additional 5% of the estate. The total of the estate now being managed for biodiversity stands at over 20% or 90,055 ha (A. O'Sullivan, 2013, pers. comm.). Therefore, Coillte is a significant contributor to the National Biodiversity Programme. To advise operational forest management staff in the management of these areas and address ongoing environmental compliance requirements, Coillte currently employs a senior ecologist, a hydrologist and four environmental officers.

Since 2001, many operational staff have undergone biodiversity training to certificate or diploma level with University College Cork. Coillte has developed biodiversity action plans for three key species, namely the Lesser Horsehoe Bat, the Hen Harrier and Freshwater Pearl Mussel and one habitat type, Raised Bog, all of which are listed as rare or endangered in Ireland under the EU Habitats and Birds Directive and for which forestry is particularly relevant to their conservation.

An Old Woodland Survey (OWS; Garrett 2001, Garrett and O'Sullivan 2001) was commissioned by Coillte in 2001 to complete the first systematic attempt in Ireland of quantifying and inventorying Ireland's old woodland sites on the Coillte estate. The survey was carried out by comparing the distribution of woodland cover as shown in the first edition of Ordinance Survey maps (1833-1844) with that mapped on the subsequent third edition (1900-1913), and lastly with the then Coillte inventory data (2000). Maps were drawn up to show where overlaps occurred with nature conservation designations such as Natural Heritage Areas and Special Areas of Conservation. The survey found that there were 27,000 ha of OWS sites on the estate, comprising 6.5% of the productive forest area. An area of 1,232 ha of OWS sites are currently being restored to semi-natural woodland under the Native Woodland Grant scheme (I. Booth, 2013, pers comm.). The scheme provides grant assistance towards the establishment costs in the first four years, but the ongoing yearly costs of maintenance are being paid for by Coillte. The company is restoring a considerable amount of other former OWS sites to semi-natural woodland, without external grant assistance.

Coillte was a major partner in the Peoples Millennium Forests Project, where over 340 ha of land was planted in 2000, (316 ha on Coillte land) using native Irish seed and also the restoration of certain native woodlands. A native tree was planted on behalf of every household in Ireland and a certificate was posted to all homes giving details about the household's tree and where it was planted. These forests continue to be managed by the company and form a lasting legacy for all to enjoy and include woodland walks, nature trails, interpretive and recreational facilities.

Habitat restoration and EU LIFE Nature projects

The company has undertaken a number of very significant EU LIFE funded projects in recent years. Between 2002 and 2007, a major blanket bog restoration project (LIFE02 NAT/IRL/8490 "Restoring Active Blanket Bog in Ireland") was undertaken on Coillte land to restore 1,967 ha of afforested peatland back to their former blanket bog status. Most of the sites were situated along the western seaboard of Ireland, with County Mayo containing the largest number. The sites were selected because they lay within or adjoined Natura 2000 sites which had been designated because of the high quality blanket bog habitat present. The main restoration work carried out was felling of the standing conifer crop, the blocking of drains, the removal of the regenerating conifers and native broadleaves where feasible, and on some sites new fencing was erected in order to exclude grazing animals. This project has significantly improved the quality and quantity of blanket bog habitat within a number of important Irish Natura 2000 sites, and has also provided important insights into blanket bog restoration in terms of appropriate methodology and the cost of implementation. The overall cost of the project was €4.19 million, 75% being funded by the EU and 25% by Coillte.

Following on from the success of the above project, Coillte, in 2004, began a new raised bog restoration project (LIFE04 NAT/IE/000121 “Restoring Raised Bog in Ireland”) with funding again from the EU LIFE-Nature Programme. A total of 14 sites comprising 571 ha were selected for the project as they were within raised bog SAC’s. While most sites selected consisted of entirely afforested raised bog habitat, some of the sites contained significant areas of open, largely intact raised bog. The main restoration work was similar to that adopted on the blanket bog and also included measures for the protection of vulnerable raised bog sites from fire, and consultation to secure control of turbary (turf cutting) rights. This project was recognised by the EU as being one of the 19 best LIFE projects completed / reported on in 2008.

In 2006, Coillte began a third LIFE project, this time on native woodland restoration (LIFE05 NAT/IRL/000182 “Restoring Priority Woodland Habitats in Ireland”), again with funding under the EU LIFE Nature Programme. Four native woodland types can be found in Ireland –yew woodland, alluvial woodland, woodland associated with limestone pavement and bog woodland are all recognised under the EU Habitats as being critically rare. Nine sites representing these woodland types were selected, totalling 551 ha. The main restoration work carried out was removal of non-native trees and shrubs, control of non-native species to facilitate natural regeneration of native woodland habitat, fencing of project sites to protect sites from grazing where appropriate and extension of yew woodlands through natural regeneration and planting of local native stock. This was a very successful project and in 2011 was recognised by the EU as one of the top six best EU Life projects completed in Europe that year. The project also won the Irish section of the UN Energy Globe Awards in 2010 and the largest project site at Clonbur on the Galway/Mayo border subsequently won an RDS/Forest Service Woodland Award.

A second raised bog restoration project (LIFE09 NAT/IRL/000222 “Demonstrating Best Practice in Raised Bog Restoration in Ireland”) was begun in 2011, involving a further 17 sites, totalling 636 ha; an additional area was added during the course of the project bringing the total area to 685 ha. The sites were identified in conjunction with the National Parks and Wildlife Service as having the best ecological value and potential for restoration of wetland conditions; five of the sites are designated as SACs and twelve as NHAs. The main work being carried out is similar to the work carried out in the previous raised bog restoration project and an additional objective of this project is to contribute to the development of best practice in the restoration of afforested raised bogs, both nationally and across the EU. The project was jointly funded by EU LIFE-Nature Programme (60%), Department of Arts Heritage and the

Gaeltacht (35%) and Coillte (5% plus the project sites totalling 685 ha).

An additional aspect of all four LIFE projects was an extensive outreach and communications programme to raise public awareness of the importance of these rare habitat types, not just in Ireland but across the European Union. Each project constructed a dedicated project website which remains online today, and public walks, events, DVDs and end of project conferences were arranged for each project. In addition, demonstration sites for each project were designated with additional signage, car parking and other facilities to encourage public use of these important sites. With regard to all of the above project sites, once the projects officially ended, normally after a four-five year period, those sites continue to be maintained, monitored and managed with nature conservation as the primary management objective; Coillte does not receive any maintenance funding to support this ongoing work.

Coillte's involvement in large nature conservation projects is listed in Table 1.

Table 1: *Coillte has been and continues to be involved in four major nationally significant nature conservation projects.*

Restoration type	Duration	Restoration area (ha)
Blanket bog restoration	2002-2007	1,967
Raised bog restoration	2004-2008	571
Raised bog restoration	2011-2015	685
Priority woodland restoration	2006-2010	551

All of the above restoration projects are an integral and very important part of Coillte's overall biodiversity programme and represent the highest level of external (European Commission) recognition of the application of environmental best practice on the Coillte estate.

Landscape design and protection

Coillte's forests occupy various upland and lowland positions throughout the country and many are in areas considered valuable from a landscape perspective and or are sensitive to landscape change. Forested landscapes can add considerable value to rural areas, and forests often form interesting and valued back-drops to rural towns and villages, when they are designed to fit in with the natural landscape. Coillte's policy has been to create forests that are productive, attractive and environmentally sympathetic in the landscape. This has been achieved by ensuring that the design of forests is in harmony with the landscapes in which they are set and that large even-aged blocks are restructured to create greater diversity in age structure and tree species composition.

Restructuring of a large even-aged block of forest usually involves dividing the original forest block into a number of areas of different shapes and sizes that will be felled and replanted in different years and the resultant forest will have a variety of ages and heights which is more visually pleasing and also of benefit to the animals living in or close to those forests. Areas that have been clearfelled and previously contained one or at most two species, generally have a broader range of species included in the replanting and broadleaves tend to be planted on parts of the sites where appropriate. Coillte has a policy of routinely training and up-skilling its forest managers in the principles of landscape design. The company has classified all of its properties into "landscape units" and these have been rated high, medium or low in terms of their landscape sensitivities; each of these ratings has specific requirements in terms of their design. In plantations, the maximum coupe size (felling block) is 20 ha in upland areas, and 5 ha in lowland areas, except where larger coupes are explicitly justified through a combination of windthrow risk, landscape features and where restructuring of existing plantation design dictates larger coupe sizes.

Coillte has also undertaken a Western Peatland Project to review its commercial strategy on forests established on peatlands along the western seaboard. It has been widely accepted by Coillte's statutory stakeholders that many of those plantations are not suitable for sustainable commercial forestry and that the best management strategy is to redesign them as environmental forests so that their social, environmental and economic contribution can be optimised in the context of a shared national sustainable land use. The principle output from the project has been a Decision Support System which now supports forest managers in making both strategic and operational decisions for individual management units in these forest areas, and has been used in the most recent review of Forest Management Plans covering a five-year period.

Wild Nephin -Ireland's first wilderness?

Coillte has also been exploring new and innovative uses of forest land in Ireland. The concept of setting aside and maintaining wild lands for the protection of natural resources and enjoyment of future generations has been evolving in other developed western countries for decades. In the United States the concept is highly developed in the National Wilderness System established in 1964 to protect wild landscapes and provide opportunities for visitors to engage in "primitive" recreation. In 2009, the European Parliament recognised the need to provide such areas in an increasingly urbanised and developed Europe and has called on member states to look at setting aside lands as wilderness or "restoring" lands to primitive qualities where inhabitants have the opportunity to engage closely with nature and the natural habitats. Given Coillte's considerable competencies in habitat restoration, its major land ownership in suitable areas and its roles in recreation and partnership building, the organisation has the potential to act on this call and contribute to the development of an important national asset for future generations.

Coillte has embarked on this process through the "Wild Nephin" initiative and together with the National Parks and Wildlife Service and Mayo County Council, has dedicated approximately 11,000 ha of land in Mayo for the creation of Ireland's first wilderness area. This initiative aims to focus primarily, though not exclusively, on concrete conservation actions targeting re-wilding of nine desired habitat types within the forested part of the identified project area. As part of a 15-year conversion plan (2014-29) the intention is the withdrawal of active forest management with a vision that wild forces of nature will ultimately become the dominant management driver of the area delivering natural ecosystem services. The objectives of this project are to convert the existing plantation forest into nine desired natural and semi-natural habitat types thereby maintaining and restoring ecosystems and their services while delivering recreation and primitive recreation opportunities to the public.

Valuation of public goods provided by Coillte

The Coillte estate produces a range of benefits for the public at large that are normally referred to as "public goods" or "ecosystem services". Producing these benefits can at times increase Coillte's costs, and/or reduce its revenue compared to what they would be if Coillte acted solely to maximise its profits from commercial forestry. Coillte is generally not compensated for the financial impact of providing many of these benefits; the exceptions to this are the provision of recreation and the co-funding of a number of LIFE nature conservation projects and the People's Millennium Forests.

Coillte and the Heritage Council in 2011, commissioned Goodbody Economic Consultants to provide an economic evaluation of three key public goods provided by the Coillte estate. As the Heritage Council is a statutory body with responsibility for built, natural and cultural heritage, it was felt that the Council was the most appropriate external agency to be involved in this evaluation.

The study concentrated on three public goods produced by Coillte;

- *Landscape*; the effect on the national landscape of the forest estate managed by Coillte. This is a general effect, or good, enjoyed by anyone who is aware of, and appreciates the effect that Coillte's forests have on the landscape. It is distinct from the benefits obtained by people who actually travel to the forest estate for recreational purposes.

- *Habitats and species*; the contribution that Coillte's forests make to biodiversity and nature conservation through the protection of habitats and species. It is the value that the public place on the fact that Coillte protects, manages and enhances certain types of habitats and so secures the continued existence of certain species and animals.

- *Cultural heritage*; the heritage features, such as monuments, protected structures and cultural features that are contained in the forest estate and protected by Coillte .This is a generalised "existence" benefit that people obtain from the knowledge that these features are being protected by Coillte.

All of these public goods values are non-use values that a large proportion of the public may derive from the existence of the Coillte forest estate and how it is managed. The production of these public goods imposes real costs on Coillte. Significant staff and resources, including regular training, are devoted to implementing the policies and procedures in relation to providing these goods.

The Discrete Choice Method was used to value the listed "Public Goods". Over 1,000 Irish residents over the age of 15, randomly selected on a clustered basis in order to be representative of the population as a whole, were interviewed. The result of the survey showed that the Irish public place a total value of €510 m per annum on the existence of these goods, broken down as follows:

- Landscape €96 m per annum;
- Biodiversity and nature conservation €322 m per annum;
- Cultural heritage €92 m per annum.

Goodbody's concluded that the specific values identified in their study for these three public goods provided by the Coillte estate were broadly consistent with similar studies carried out in Ireland and other jurisdictions for similar public goods.

Conclusion

Coillte has been and is involved over many years in significant developments in the area of recreation, biodiversity and nature conservation, habitat restoration in both blanket and raised bogs and priority woodlands, landscape design and protection of cultural heritage. Certain aspects of this work were a prerequisite in obtaining international forest certification. While some funding has been received for recreation in recent years, and in the establishment of LIFE projects, the underlying position is that Coillte provides a wide range of public goods that it funds out of its own resources without adequate compensation and recognition by the State.

This situation is in stark contrast to many other countries where significant annual exchequer funding is given to their forest companies for the provision of public goods. It is important that Coillte's contribution to the provision of public goods is formally recognised by Government and that appropriate annual funding mechanisms are put in place to compensate the company for this expenditure. In regard to the EU, consideration should be given to the provision of maintenance funding for a number of years after the initial projects are completed.

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References

Anon. 1985. Report of the Minister for Energy on the Forest and Wildlife Service.

Coillte. 2002. *Restoring Active Blanket Bog in Ireland*. Available at www.irishbogrestorationproject.ie [Accessed November 2016].

Coillte. 2004. *Restoring Raised Bog in Ireland*. Available at www.raisedbogrestoration.ie [Accessed November 2016].

Coillte. 2005. *Recreation Policy, Healthy Forests, Healthy Nation*. Internal Coillte report.

Coillte. 2005. *Restoring Priority Woodland Habitats in Ireland*. Available at www.woodlandrestoration.ie [Accessed November 2016].

Coillte. 2009. *Demonstrating Best Practice in Raised Bog Restoration in Ireland*. Available at www.raisedbogrestoration.ie [Accessed November 2016].

Fitzpatrick Associates. 2005. *The Economic Value of Trails and Forest Recreation in the Republic of Ireland*.

Garrett, W. 2001. *Woodland History Survey of the Coillte Estate*. Internal Coillte report.

Garrett, W. and O'Sullivan, A. 2001. Coillte Old Woodland Survey - July 2001. *The Irish Scientist Yearbook 2001*. Samton, Dublin.

Goodbody Economic Consultants. 2011. *Valuation of the Public Goods provided by Coillte in Landscape, Habitats and Species and Cultural Heritage*.

Neville, P. 2007. Nature conservation and biodiversity initiatives in Coillte's forests. Internal Coillte publication.

O'Sullivan, A. 2004. Enhancing biodiversity in commercial forestry - Coillte's approach. In *Opportunities for biodiversity enhancement in plantation forests*. Ed. MacLennan, L. Proceedings of the COFORD Seminar, October 2002, Cork. COFORD, Dublin.

Trees Woods and Literature – 40

Poplar Memory

I walked under the autumned poplars that my father planted
On a day in April when I was a child
Running beside the heap of suckers
From which he picked the straightest, most promising.

My father dreamt forests, he is dead –
And there are poplar forests in the waste places
And on the banks of drains.

When I look up
I see my father
Peering through the branched sky.

This poem was first published in 1972 (Kavanagh) and is now widely available in the Modern Classics series published by Penguin (Quinn, 2005). Patrick Kavanagh was born in 1904, the eldest son of Bridget and James who combined shoe making and repair with farming in Mucker in the parish of Inniskeane, Co. Monaghan.

Kavanagh reluctantly followed in father's footsteps but, diverted by literature, proved unsuccessful both as a cobbler and farmer. He eventually left the family farm and after some early publishing success in London, he took up permanent residence in Dublin in 1939.

This poem dates from the period prior to 1939 when Kavanagh's farming work restricted him to "reading and writing poetry after hours, usually by candlelight in an upstairs room, away from the hurly-burly of the family kitchen" (*ibid*). The eldest son of 10 siblings he was expected to stay at home on the family farm, even though it was apparent from an early age that he was clearly gifted as a poet. He left school at 13 years of age and received no further formal education.

Kavanagh struggled as a poet for much of his life due to poverty, poor health and addiction to gambling and alcoholism. Moreover, his cantankerous nature didn't endear him to fellow poets and writers. However, his stature as a major Irish poet has been acknowledged among critics and fellow poets, in particular Seamus Heaney, who wrote (O'Driscoll, 2008): "Kavanagh gave you permission to dwell without cultural anxiety among the usual landmarks of your life."

Trees feature sporadically in Kavanagh's early work, not unsurprisingly as the surrounding landscape was largely tree-less and even today Monaghan ranks as one of the least forested counties in Ireland. However, there are a number of beautiful insights to small-farm life and at least the possibility of trees and forests. He even tried his hand at planting himself, which he recounts in "Beech Tree" (Quinn, 2005):

I planted in February
A bronze-leafed beech
In the chill brown soil
I spread out its silken fibres.

But like his farming endeavours, the end result is failure, as he admits.

It is August now, I have hoped
But hope no more –
My beech tree will never hide sparrows
From hungry hawks.

The moist soils around Inniskeane proved more conducive to poplar growing and Kavanagh was aware of this, poetically, if not silviculturally. In an early poem "To a Late Poplar" he compares the tree to "Not yet half drest, / O tardy bride"

Although, unlike Heaney and Frost, he had no nearby forests to inspire woodland or tree poems, he connects eloquently with an imagined forest in "Poplar Memory". Kavanagh's poplars act as a metaphor in recreating the memory of his father. His father, a more practical man than his son, saw the worth of planting quality suckers "From which he picked the straightest, most promising". He also knew that trees had a role to play in farming at least "in the waste places / And on the banks of drains".

Unlike the poet's beech, many of James Kavanagh's poplars still survive around Mucker. The poet keeps them alive in memory and while references to trees fade from his later poems, he revisits this landscape in works such as "Wet Evening in April" where "The birds sang in the wet trees / And as I listened to them it was a hundred years from now...". A hundred years on, it is pretty certain that people will still be listening.

Patrick Kavanagh died on 30th November 1967 in a Dublin nursing home, 12 years after he was diagnosed with lung cancer.

Donal Magner
Wicklow

References

Kavanagh, P. 1972. *The Complete Poems*. Collected, arranged and edited by Peter Kavanagh. The Peter Kavanagh Hand Press, New York.

Quinn, A. (Ed.) 2004. *Patrick Kavanagh: Collected Poems*. Penguin Modern Classics, London.

O'Driscoll, D. 2008. *Stepping Stones: Interviews with Seamus Heaney*. Faber and Faber Limited, London.

Society of Irish Foresters Study Tour to Bordeaux

11th – 16th October 2015

On Sunday, 11th October, forty one members of the Society of Irish Foresters assembled at Dublin Airport to begin the 72nd study tour to Bordeaux and the Aquitaine region of south-west France. Surprisingly, despite the proximity, this was only the Society's second time to visit France. In 1991, we toured eastern France - see Irish Forestry, Vol. 49, 1992.

Our tour began with a visit to the Regional Forest Office in central Bordeaux, for an official welcome and a very informative, introductory lecture on forestry in the region. On the following days we visited the chestnut (*Castanea* spp.) forests of the Dordogne, protection forests near Arcacahon, INRA's impressive forest research campus, the commercial forests of maritime pine (*Pinus pinaster* Aiton) and a "climate change" arboretum.

The high point of this year's study tour was undoubtedly our visit to the forest research campus of the National Institute of Agronomic Research (INRA) at Pierroton, 45 km south west of Bordeaux. Here we were introduced to INRA's cutting edge forest genetics programme, which has three objectives: to produce enhanced forest reproductive material, to address the challenges presented by climate change and to select for improved pathogen resistance. INRA's network of research support structures is certainly impressive, particularly its forest advisory and co-operative groups which work together to develop the private forestry sector. At the heart of this industry is a clearly focused and well resourced forest research programme which drives the industry's innovation and development. Significant developments in forest genetics and advances in cultivation, establishment and silvicultural methods are the practical results of France's long-term investment in forest research. As a result, France's forestry sector is well placed to address the many challenges, and also the opportunities, which will arise over the coming years. There are many important lessons here for Ireland's forestry industry.

Overnight – Bordeaux Pat O'Sullivan, Tour Convenor

Monday, 12th October

Bordeaux is a handsome city which can boast a proud 2,600-year history. Located in the southwest of France on the river Garonne, it has a population of 240,000. The architecture of the city centre is primarily three or four storey limestone buildings of classical design with shops or restaurants on the ground floor and offices and/or living accommodation on the upper floors. The majority of these buildings were constructed in the 18th and 19th centuries during a period when the mediaeval city was torn down

Figure 1: *Place de la Bourse in central Bordeaux.*

and virtually rebuilt to facilitate population growth and to improve sanitation by increasing airflow through the new, wider streets. Air pollution during the industrial age and the rise in popularity of motor cars resulted in the facades of all the buildings becoming blackened and unattractive. A major rejuvenation project during the 1990s focused on cleaning of the blackened facades of these fine buildings.

In addition, strictly enforced traffic controls were introduced. An extensive electric tramway, which is very similar to Dublin's LUAS, facilitates movement through the city. In the city centre area, the overhead power lines are dispensed with and an ingenious ground level power supply provides the electricity for the trams thus making the transport system very unobtrusive. In 2005, Bordeaux Centre was awarded a coveted UNESCO World Heritage status.

In the afternoon of Day 1 of our tour, fortified by a superb lunch at Le Bistrot des Quinconces, we visited the Regional Forestry headquarters in central Bordeaux, for an introductory lecture on forestry in the Aquitaine region which focused on its history, silviculture and forest fire risk assessment and management. La Maison de la Forêt is home to the Union of the Southwest Foresters whose 6,340 members own 65% of the private forests in the region. The Union represents the interests of forest owners on a wide range of issues including laws and regulations, investment, forest protection and it lobbies on their behalf at local, national and international level.

In France there is 14.8 million ha of forest, representing 27% land cover. Forests are predominantly privately owned - 74% of forests are owned by individuals or groups, the remainder is state owned. France boasts the highest standing volume of timber in Europe and ranks 3rd in percentage forest cover after Sweden and Finland. The timber industry has an annual turnover of €40 billion and employs 230,000 people.

The Aquitaine region of France has 1.78 million ha of forest, equivalent to 42% land cover. In this region 92% of the forests are privately owned, which is far higher than the national average. The forestry industry in Aquitaine has a turnover of €2.59 billion and employs about 34,000 people. Annual timber production is 6 million m^3 of conifers and 360,000 m^3 of broadleaves.

There are three distinct environment types in the Aquitaine region: Dordogne/ Garonne which is characterised by broadleaf species such as oak (*Quercus* spp.), sweet chestnut (*Castanea sativa* Mill.) and poplar (*Populus* spp.); Adour Pyrenees which is mountainous and is predominantly beech (*Fagus sylvatica* L.) and oak; and Landes de Gascogne which is noted for its maritime pine.

The Landes de Gascogne has undergone a significant change in land use over the course of the previous two centuries. In the early 18th century the area was heathland which was used for sheep farming while currently it has more than 90% forest cover. At 1.1 million ha it is the largest plantation forest in Europe – a monoculture of maritime pine, originally planted for coastal erosion control and sand dune stabilisation, later it supported a major resin production industry and in more recent times the focus has shifted to commercial sawlog production while, in coastal areas, a significant tourism industry has developed. The maritime pine tree improvement programme began in the mid-1950s and has led to a large increase in sawlog production.

Currently, one of the main objectives of the Union of Southwest Foresters is to help its members reduce the damage caused by forest fires. The cornerstone of this service is a comprehensive GIS-based risk assessment and mitigation procedure, provision of fire insurance, the development of fire management plans and provision of fire patrols and additional monitoring during periods of greatest fire risk. The Union also assists members with funding through a low interest rate loans and a 10-year forest savings plan. It also draws up forest management plans and negotiates timber sales on behalf of its members.

Overnight – Bordeaux Chris Mc Gurren

Tuesday, 13th October

We departed Bordeaux at 8.30 am and headed for the Dordogne which is approximately 100 km east of Bordeaux on the A89 Auto Route. Our leader for the day was Christophe Orazio, Director EFI-Atlantic. The main tree species in the Dordogne are sessile oak (*Quercus petraea* (Matt.) Liebl.), maritime pine and chestnut. Just over 50% of the land area of the Dordogne is forested and 64% of this is composed of broadleaves. Traditionally these stands were coppiced, mainly for firewood. However, the coppice has grown old and has begun to degenerate. After centuries of continuous coppicing it has become susceptible to disease, and current policy is to replace this low value coppice, especially chestnut coppice, with higher value maritime pine.

At our first stop we were joined by Gerome Carnet who is employed by Centre National de la Propriété Forestière (CNPF) as a forest advisor to private forest owners. This service is funded by a national land tax. More than 90% of the forests in the Dordogne are privately owned and the average size is just 4.0 ha. The main problems in this area arise from the very diverse objectives of the forest owners. Significant effort is invested in trying to organise them into groups. Joint management of the forests is carried out on behalf of these groups by Gerome Carnet and his colleagues, although no formal agreement is made between the owners. There are very few large, well-managed forest properties in the Dordogne.

Our first stop was at an area of poor quality chestnut coppice. The coppice was cleared by a feller-buncher with a rotating disc harvester head. This machine has greatly aided the transition from coppice to pine as it is fast and can cut lower down on the stem than chainsaws, which facilitates ground preparation for the subsequent restocking. The chestnut was stacked on the roadside for the firewood market. Income from the firewood sale is shared among the forest owners on the basis of the area each one owns. Paper mills also buy this chestnut material, but the logs are less attractive for milling because of the high proportion of dead and decaying logs in each consignment. There were also some very fine oak stems stacked on the roadside. These are individually stamped and the income for each stem goes to the individual landowner. Good quality oak is highly prized by furniture makers and the wine industry where the first 2 m of the stem can command prices between €400 and €600 m^{-3}.

Figure 2: *High quality oak logs which will be used to make "premier cru" wine barrels.*

Harvesting takes place within a policy and legal framework which is agreed at national level. In the Dordogne, a licence is required for felling an area >1.0 ha. The licence carries a restocking requirement. In the past, chemicals such as Garlon® could be used to control vegetation but it is prohibited now. At our next stop, two methods of ground preparation (complete ploughing and mulching plus harrowing) were being assessed. The aim is to eliminate competing vegetation for the first year and thus give the trees a chance to get established. The trees are planted in strips 4.0 m apart with closer spacing along the lines in order to increase stocking levels. After a few years it is possible to scarify between these strips. Mulching costs €1,000 - €1,500 ha^{-1}. Maritime pine was replanted on the site. The rotation length is 35 to 40 years and thinning is scheduled for years 15, 20 and 30. The expected yield class is 8 to 10 m^3 ha^{-1} yr^{-1}. Natural regeneration would cost approximately €2,500 ha^{-1} on this site. Restocking with oak is a possibility but it was felt that there would be too much competition from re-growth of chestnut coppice to make this a worthwhile option. It is always a major challenge is to get the forest owners to reinvest as they expect the income from clearing the old coppice should pay for the establishment of the new crop. The replanting requirement is now much more rigidly enforced due to pressure on France's national timber resource.

We then visited a reforestation site where sessile oak was planted with a mix of *Acer* and *Prunus* species in an attempt to increase species diversity. However, the *Prunus* seedlings had failed because the soil here was unsuitable. Close by, a small plantation of loblolly pine (*Pinus taeda* L.) was being assessed as an alternative to maritime pine. Initial indications are that it is quite windfirm and can grow faster than

Figure 3: *A 10-year-old stand of intensively managed, short rotation poplar.*

maritime pine, but it will thrive only on good quality sites and is more prone to basal sweep than maritime pine. Loblolly pine is also quite susceptible to attack by the spruce bark beetle[1].

Our final stop of the day was at a very impressive stand of poplar. In the Dordogne there is a strong market for poplar timber, which is used to produce boxes and baskets for the fruit and vegetable industry in the south of France. It is also an important element of the plywood industry, although this has declined in recent years.

Poplar provides an important source of income for the forest owner. Cultivation is very intensive but the returns are attractive due to the short rotation length of just 12 years. The main challenge is to grow the crop as fast as possible and to prune it early on. The standing volume after 12 years is approximately 200 m^3 ha^{-1} and the average price is €50 m^{-3}. The net income per tree is approximately €30. Harvesting will be done by chainsaw as this causes less damage to the valuable logs. All branch wood is shredded and removed from the site to reduce the spread of disease. The trees cost €5 each and they are planted at 7 × 7 m spacing (approx. 200 plants ha^{-1}).

In France there are currently about 30 poplar clones in use, mostly North American and European varieties. There is a constant need to develop new clones due to sanitary problems with poplar-rust, aphids etc. The objective of breeding programmes is to develop greater resistance to disease. If disease enters a plantation, treatment is very expensive. The best defence is to diversify by planting as many clones as possible in each locality to reduce susceptibility to disease.

Overnight – Bordeaux Pacelli Breathnach

Wednesday, 14th October

On Wednesday, we travelled south west to Pierroton to visit INRA's huge Forest Research Campus. INRA is France's national institute for agricultural research. Established shortly after World War II in May 1946, its original objective was stated very simply as being – *to feed France*. It has since diversified greatly. The Pierroton research centre is one of the two main forest research stations in France and is now 50 years in existence. Here its scientists conduct innovative and targeted plant science, ecological and environmental research in response to current challenges in the agricultural, forestry and aquaculture sectors. The forest research centre alone has a staff of about 220 people who work with partners such as the European Forest Institute (EFI); the French Institute of Technology for Forest-based and Furniture Sectors (FCBA), which is a national organisation for applied research working on nursery production and forest products; and Alliance, which is a cooperative of private forest owners engaged in forest management, establishment and harvesting.

Christophe Orazio, Director of EFI-Atlantic gave us a presentation about his

[1] Trees in the genera *Picea, Abies, Pinus* and *Larix* are the bark beetles' trees of choice.

organisation. EFI-Atlantic was established in 2009 in response to increased forest industry globalisation, climate change, trans-national pollution concerns, and greater European integration. EFI-Atlantic focuses on the sustainable management and competitive utilisation of forests in diverse geographical regions stretching along Europe's Atlantic rim from southern Portugal up to northern Scotland. It is currently involved in four strategic areas: integrated management of forest risks; facilitation of adaption to climate change; sustainable intensification of wood production and provision of ecosystem services. EFI-Atlantic has a membership of 130 research organisations from 36 countries, mainly in Europe.

Loic Cotton of Alliance Forêts Bois then followed with a presentation on his organisation. Alliance is a large cooperative of 44,000 forest owners spread across five regions of France, and employs about 500 staff. In 2014 it had €30 million in assets and a turnover of €170 million. It sold 2.8 million m^3 of timber and reforested 15,400 ha. It provides the full range of forest management services to its members. While it currently exports wood and wood products to 10 countries, just over 90% of its produce is sold in France.

Our first stop was at the site of a large climate change research experiment in which there are 38 different species of conifers and broadleaves planted in replicated plots, with three provenances of each species. This trial is replicated in 38 other areas from Portugal to Scotland and the Azores. Unfortunately, Ireland is not represented in this important trial as no Irish research organisation was able to participate. During the period 2009 – 2013 the unique series of trials established by this project, whose sites range in location from 37 to 58° latitude, to monitor productivity changes and test the adaptive capacity of the species to climate change. All the seed used in the trial was sown in a single nursery in France and plants were subsequently delivered to the various sites. An international database has been developed which is coordinated by EFI-Atlantic. Plant health assessments (insect damage, frost damage and drought) are undertaken each year. Meteorological conditions are also recorded on the database. It is likely to be 15 years before any meaningful trends emerge from this experiment.

We also visited an experiment which was laid down in 2009 to assess the growth of single species and various species mixtures under a range of management treatments. The species being tested included *Pinus pinaster* and *Pinus taeda*, a range of Eucalyptus species in mixture with *Pinus pinaster* and the hybrid *Eucalyptus gundal* (*Eucalyptus gunnii* Hook.f.× *Eucalyptus dalrympleana* Maiden) for biomass production. Increasing plant nutrition, through the use of legume species, is also being assessed here.

We then returned to the main campus at Pierroton where we toured the impressive FCBA Technical Research Centre which studies genetic improvement, particularly of maritime pine and loblolly pine. The overall objective of current research is to increase the productivity of planted forests. Some very impressive results have already been achieved. FCBA scientists have successfully developed the *Eucalyptus gundal* hybrid, which is frost tolerant to -15 °C. They have undertaken some testing in relation to genetic modification of *Pinus pinaster*, but under current legislation this material cannot be tested in the field. They also have a laboratory where several thousand genotypes of a range of tree species are stored in liquid nitrogen for conservation purposes.

In the afternoon we travelled further west to Arcachon to see protection forests of maritime pine which were established along the Atlantic coastline during the mid-19th century. We were met by Francis Maugard, the forest manager and assistant Fabrice Caire of the Office National des Forêt (ONF). They explained that all forest operations are prohibited in a 200 m wide strip immediately behind the sand dunes. Further inland limited minor forest operations are permitted and beyond that normal forest management operations are allowed. The forest is managed as an even-aged plantation on a rotation length of 50-60 years during which four and sometimes five thinning operations are carried out, resulting in a final crop of 250 stems ha^{-1}. Natural regeneration post clearfell is generally reliable but it may be supplemented by seeding where required. The target restocking level is 1,250 stems ha^{-1} and it may sometimes be necessary to respace the naturally regenerated seedlings. Maritime pine was originally planted along this coastal strip of 230 km in the mid-1800s in an attempt to protect the land from coastal erosion and this has resulted in a single forest block of 60,000 ha. An interesting feature of the forest understory is the prevalence of *Arbutus unedo* (L.), the strawberry tree.

Figure 4: *Tree-breeding laboratory at INRA's forest research campus near Pierroton, south west of Bordeaux.*

Figure 5: *Europe's tallest sand dune (Grande Dune du Pilat) overlooks 1.1 million ha of maritime pine which stretches to the horizon.*

ONF forests are required to be multi-functional. The management objectives here at Arcachon are erosion control, provision of recreation by maintaining walking and cycle tracks, maintenance of biodiversity, and wood production. Public access is restricted to certain areas within the forests and routine patrols are carried out to control anti-social behaviour. Interestingly, the forester rangers in this area carry guns, but do not have the power of arrest. Forest fires are a significant risk for much of the year. The most common cause of forest fires is lightning strike. Remotely monitored fire towers are built at 10 km intervals to detect outbreaks.

We concluded our afternoon by visiting and climbing the sand-dune at Pyla (Grande Dune du Pilat). With a current height of 110 m this is the tallest sand-dune in Europe and offers fine panoramic views looking out on the Atlantic Ocean and inland over endless forests of maritime pine or as the local forester put it – "to the west the blue ocean, to the east the green ocean".

Overnight – Bordeaux Eugene Griffin

Thursday, 15th October

On the fifth day of the study tour we headed east from Bordeaux with Mme Amelie Castro (CRPF), to begin a day which highlighted the critical importance of long term research, innovation and collaboration. The role of CRPF (Le Centre Regional de la Propriété Forestière) is to direct, assist and improve the management of private forests in France.

At the first stop, a wind-blow restock planting site we met Loic Cotton, Director of Alliance Forêts Bois, the forest owners co-operative. The restock site had a very sandy soil (98% sand). The water table was described as being too high in winter and too low in summer. It costs an average of €1,000 ha^{-1} to restock this type of site.

Reforestation of these sandy site types involves the following operations:

- **clear brash** – the contractor uses a locally designed machine, which is essentially a roller with large blades attached, which are designed to chop up the branches. The roller is tractor drawn but ground compaction is not a problem as the soils are sandy.
- **plough** down to a depth of 40cm and apply mineral phosphate fertiliser at 90 kg ha^{-1}.
- **compacting** – this is done to create a better planting medium by breaking up larger soil lumps and expelling excess soil air. It also helps to control vegetation.
- **planting** with improved maritime pine containerised plants at 4 by 2 m spacing. Improved plants cost €0.25 each plus a further €0.25 each for planting. On average workers plant 1,500-2,000 plants a day depending on the site. These containerised plants have a 6-8 month supply of phosphorus in the container.

In the third year mechanical inter-row cleaning is carried out to reduce vegetation growth and in the process remove a potential fire hazard. The rotation length is 35-45 years and first thinning is carried out at 12 years of age. At clearfell the mean DBH is 35 cm and the average tree size is 0.8-1.2 m^3. The standing volume is 350 m^3 m^{-1} and average revenue is €10,000 ha^{-1}.

Landes de Gascony has very poor quality agricultural land with the result that the average distance between villages is almost 15 km, which is a very low density for France. These sandy soils in the Mimizan area were first planted in the mid-19th century. Previously sheep farming was the main industry, but forestry is now the principal employer in the area. In the 1960s, resin production was the main source of revenue, but now it is wood production.

Environmental groups are strongly opposed to monocultural planting of large tracts with Maritime pine followed by clearfelling. However, a biodiversity inventory carried out 10 years ago found that birds, which are normally associated with open land, were now using clearfell coupes, moving from one to the next and their populations were increasing. Alternative land uses such as maize or solar farms provide much less biodiversity. Returning the land to sheep grazing is not an option as these soils are too low in nutrients to support modern sheep breeds. Overall, it appears that forestry is the best land use option for biodiversity.

Our second stop was in Mimizan, a town with a population 13,000 people. Thanks to the extensive forests (83% forest cover) and its proximity to the Atlantic Ocean, the area is now an important tourist destination. However, forest fires are a serious risk.

In 2015 there were 1,700 separate incidents. The fire risk season extends from March to August and young forests (less than 20 years old) are the most vulnerable. Natural causes, such as lightning storms cause 19% of the fires, but 81% of all fires in the area are the result of human activity - a very low percentage of these are caused by arson attack. In the local community hall we met Jean Marc Billac, Benoît Bodennec and Sophie Gaston from the Association Régionale de Défense des Forêts Contre l'Incendie (DFCI-Aquitaine) who explained the work of their organisation and kindly provided refreshments and tourist information on the area.

DFCI-Aquitaine is a unique, community based organisation, which was formed in August 1949 following the years of "Les Grands Feus" – a period from 1940-1949 when 450,000 ha of commercial forests were destroyed by fires and resulted in the death of 82 villagers/fire-fighters in huge conflagrations to the south of Bordeaux. DFCI's main objective is to prevent forest fire by improving forest management practices. DFCI coordinates the work programmes proposed by DFCI Associations by way of Departmental Unions.

DFCI supports the efforts of forest fire-fighters by:

- building access tracks and bridges to give fire-fighters faster access within the forest;
- providing at least one reservoir or "water point" per 500 ha of forest;
- initiating information campaigns to alert all forest users and visitors to the dangers posed by forest fires;
- building and maintaining fire breaks in the forest and especially alongside roads;
- assisting forest owners to monitor fires sites after they have been extinguished.

Our third stop of the day was a second generation maritime pine seed orchard close to Mimizan where our guide, Annie Raffin (INRA), gave us an excellent presentation on tree improvement research at the Office National de Forêt (ONF) seed orchards in the Aquitaine. Maritime pine is indigenous to the area and in the early 1950s work began with the creation of a "common garden" or small arboretum to compare maritime pine trees from throughout its natural range. This was the earliest, scientific trial which compared maritime pine populations using replicated plots, thus enabling statistical analysis to be undertaken. The first step in the maritime pine improvement programme, which began in the 1960s, was to compare the growth and performance of the provenances in this trial. There were huge variations between the provenances, but the local Landes provenance, provided greater timber production and greater frost resistance than the other provenances. The next step was the selection of 350 plus-trees, based on the superiority in growth rate and form, in forests throughout the Landes forest. Following this a recurrent selection and then a backward selection of the best parents was used to establish a seed orchard. A new seed orchard was established from each generation of the breeding programme, 200 ha for each generation. The seed orchard we visited was a 83-ha second-generation seed orchard which was planted at wide spacing to encourage greater cone production. There can be up to 30% contamination by pollen from surrounding non-orchard trees, reducing genetic gains by up to 50%.

Since the 1960s the important selection criteria for ONF's tree breeding programme were growth rate and stem straightness; more recently wood quality has been favoured. The timber industry is satisfied with the wood quality gains achieved and it is now looking for increased volume growth. The challenge is to deliver these increased growth rates without compromising wood density levels. Improved plant material is used exclusively on reforestation sites. ONF's breeding programme is publically funded so improved seed is available to all nurseries owners and there are no royalty payments built into the cost of the seedlings. This is done in the national interest.

It is important to maintain the broad genetic diversity of maritime pine as this ensures greater adaptability in the face of an ever changing environment where climate change and new pests and diseases are real and imminent threats. An EU project has been set up to conserve the national forest resource of maritime pine by planting five "conservation units" or gene banks along the coast. Each plot is 25 ha and the trees are allowed to pollinate naturally.

An interesting development, which underlines the value of long-term research, is a refinement of the tree breeding programme which selects for disease resistance.

Figure 6: *Amilie Castro (CRPF) and Annie Raffin (INRA) outline current tree improvement research at the* Pinus pinaster *seed orchard near Mimizan in the Landes.*

Different selected families of maritime pine are planted in *Fomes annosus*-infected plots to see if any population exhibits stronger resistance. INRA scientists are also selecting for improved drought resistance in maritime pine.

The final stop of the day was at a clearfell site where tree stumps had been removed for sale as boiler fuel. In the first plot we visited, the stumps had been removed recently; in the second plot, the stumps had been removed almost nine months previously and were cleaner owing to the effects of washing by frequent rainfall. The preferred method is to chip the stumps on site but where it is not possible to set up the chipper, full stumps are transported to the customer. The revenue from stumps is €2 $tonne^{-1}$ and 35 tonnes ha^{-1} are removed. The cost of stump removal is primarily dependent on the stump diameter. Stump removal also reduces the cost of site preparation for the succeeding crop.

There was some heated discussion about the impact of stump removal on soil fertility. A comparison of growth rates on sites where stumps were either removed or retained has shown no significant difference to date on the growth rates of the next-rotation crop. However, there is a loss of soil carbon due to site preparation and it takes seven years for this to be restored. The spreading of ash from wood boilers on reforestation sites is not allowed at present as the ash is classified as a waste material. In this locality there is a tradition of stump harvesting, as it has been practised since the 19th century to manufacture tar for local fishing boats.

Overnight – Bordeaux Clodagh Duffy

Figure 7: *"Rue Sullivan" in central Bordeaux – a reminder of the many historic links between Ireland and Bordeaux.*

Tour Participants (41)

Frank Barrett, Pacelli Breathnach, Richard Clear, Philip Comer, John Connelly, Bob Dagg, Padraig Dolan, Clodagh Duffy, Niall Farrelly, P.J. Fitzpatrick, Jerry Fleming, Gerhardt Gallagher, Tony Gallinagh, Sean Galvin, Eugene Griffin, John Guinan, George Hipwell, Mark Hogan, Catherine Hutchinson, Kevin Hutchinson, Tim Hynes, John K Kelly, Kevin Kenny, John Madden, Chris Mc Gurren, Tom McDonald, Willie McKenna, Liam Murphy, Frank Nugent, Benny O'Brien, Michael O'Brien, Kieran O'Connell, Colm O'Dwyer, Paddy O'Kelly, Owen O'Neill, Pat O'Sullivan, Richard Romer, Mary Treacy, Padraic Treacy, Gabriel Tucker, Trevor Wilson.

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

100 Contemporary Wood Buildings by Philip Jodidio. Published by Taschen. 2015.

A Dictionary of Scientific Tree Names: Covering over 450 species of Trees Found in Britain by Ian Parsons. Published by Create Space Independent Publishing Platform. 2015.

A Geography of Hope: Saving the Last Primary Forests by Cyril Kormos, Russell A Mittermeier, Tilman Jaeger and Brendan Mackey. Published by Conservation International in their CEMEX Nature Series (4). 2016.

A Natural History of the Hedgerow and Ditches, Dykes and Dry Stone Walls by John Wright. Published by Profile Books. 2016.

A Tale of Trees: The Battle to save Britain's Ancient Woodlands by Derek Niemann. Published by Short Books. 2016.

Afforestation, Reforestation and Forest Restoration in Arid and Semi-arid Tropics: A Manual of Technology and Management by Panna Ram Siyag. Published by Springer. 2016.

Ancient Skies and Ancient Trees by Beth Moon; with essays by Jan Grecevich and Clark Strand. Published by Abbeyville Press. 2016.

Arboreal: Words from the Woods by Evie Wyld, Ali Smith, Alan Garner, William Boyd, Sara Maitland, Helen Dunmore, Germaine Greer and Kathleen Jamie. Published by Little Toller Books. 2016.

Baobabs of the World: The Upside Down Trees of Madagascar, Africa and Australia by Andry Petignat. Published by Penguin Random House, South Africa. 2016.

Broadleaf Forestry in Ireland by J. Huss, P.M. Joyce, R. MacCarthy and J. Fennessy. Published by COFORD, Department of Agriculture, Food and the Marine. 2016.

Celebrating Soil: Discovering Soils and Landscapes by Megan R. Balks and Darlene Zabowski. Published by Springer. 2016.

Challenge of the Big Trees: The Updated History of Sequoia and Kings Canyon National Parks by William C. Tweed and Lary M. Dilsaver. Published by George F. Thompson Publishing. 2016.

Dipterocarp Biology, Ecology and Conservation by Jaboury Ghazoul. Published by Oxford University Press. 2016.

European Atlas of Forest Tree Species. Edited by San-Miguel-Ayan, J., de Rigo, D., Caudullo, G., Houston Durrant, T. and Mauri, A. 2016. Publication Office of the European Union, Luxembourg. 2016.

Forest Hydrology: Processes, Management and Assessment by D. Amatya, T. Williams, L. Bren and C. de Jong (Editors). Published by CABI. 2016.

Global Deforestation by Christine Runyan and Paola D'Odorico. Published by Cambridge University Press. 2016.

***Hawthorn – The Tree That Has Nourished, Healed and Inspired throughout the Ages** by W. Vaughan. Published by Yale University Press. 2016.

***Heritage Irish Plants**. Edited by B. Sayers and P. Tobin. Published by Irish Society of Botanical Artists and Irish Garden Plant society. 2016.

Historic Redwood National and State Parks: The Stories Behind One of America's Great Treasurers by Gail Jenner. Published by Lyons Press. 2016.

Illustrated Guide to Oaks by Antoine Le Hardy de Beaullieu and Thierry Lamant. Published in 4 volumes by Edilens. 2016.

Making the Most of Indigenous Trees (3rd Edition) by Fanie Venter (author), Julye-Ann Venter (author), Pitta Joffe (illustrator). Published by Briza Publications. 2016.

Managing Your Woodlands for Wildlife (New Edition) by David Blakesley, Peter Buckley, Tharada Blakesley and Margaret Hanton. Published by Pisces Publications. 2016.

Maple Syrup: An Introduction to the Science of a Forest Treasure by Michael A. Rechlin. Published by McDonald and Woodward. 2016.

Monet's Trees: Paintings and Drawings by Claude Monet by Ralph Skea. Published by Thames and Hudson. 2015.

Nature's Temples: The Complex World of Old-Growth Forests by Joan Maloof. Published by Timber Press. 2016.

***Norwegian Wood – Chopping, Stacking and Drying Wood the Scandinavian Way** by L. Mytting. Published by MacLehose Press. 2016.

No Timber Without Trees: Sustainability in the Tropical Forest by Duncan Poore. Published by Earthscan. 2016.

On the Forests of Tropical Asia: Lest the Memories Fade by Peter Ashton. Published by Kew Publishing. 2015.

Pests of Landscape Trees and Shrubs: An Integrated Pest Management Guide (3rd Edition) by Steve H. Dreisradt. Published by University of California Agriculture and Natural Resources. 2016.

Pests of Ornamental Trees, Shrubs and Flowers: A Colour Handbook (2nd Edition) by David Valford. Published by CRC Press. 2012.

Plantations and Protected Areas: A Global History of Forest Management by Brett Bennett (author), and Michael Egan (editor). Published by MIT Press. 2016.

Roots and Root Systems of Trees by Jan Jenik, Miloslav Studnicka and Jan Cermak (Bi-Lingual). Published by Liberec Botanical Gardens. 2014.

Sacred Trees of Ireland by Christine Zuchelli. Published by The Collins Press (New Edition). 2016.

***Shades of Green: An Environmental and Cultural History of Sitka Spruce** by Ruth Tittensor. Published by Oxbow Books. 2016.

Silviculture: Concepts and Applications. Third Edition by Ralph D. Nyland, Laura S. Kenetic, Kimberley K. Bohn, and Susan L. Stout. Published by Waveland Press. 2016.

The Ancient Yews: A History of *Taxus baccata*. (Third Edition) by Robert Bevan Jones. Published by Windgather Press 2016.

***The Book of Leaves: A Leaf-by-Leaf Guide to Six Hundred of the World's Greatest Trees** by Allen J. Coombes and Zsolt Debreczy. Published by Ivy Press. 2016.

The Botanical Treasury by Christopher Mills. Published by Andre Deutsch Ltd. 2016.

The Cabaret of Plants by Richard Maybe. Published by Profile Books. 2015.

The Forest Certification Handbook (2nd Edition) by Ruth Nussbaum and Markku Simula. Published by Taylor and Francis. 2016. A Volume in the Earthscan Forest Library Series.

The Genus Betula: A Taxonomic Revision of Birches. Reprinted with corrections by Kenneth and Hugh A. McAllister. Published by Kew Books. 2016.

The Hidden Life of Trees: What they Feel, How they Communicate – Discoveries from a Secret World by Peter Wohlleben. Published by Greystone Books, Canada. 2016.

***The Hurley Maker's Son** by Patrick Deeley. Published by Doubleday Ireland. 2016.

The Invention of Nature: The Adventures of Alexander von Humboldt, the Lost Hero of Science by Andrea Wulf. Published by John Murray. 2015.

The Kew Book of Botanical Illustration by Christabel King. Published by Search Press (UK). 2015.

The Kew Plant Glossary: An Illustrated Dictionary of Plant Identification Terms (2nd Edition) by Henk Beentje and Juliet Williamson. Published by Kew Books. 2016.

The Land of the Green Man: A Journey Through the Supernatural Landscapes of the British Isles by C. Larrington. Published by I.B. Tauris. 2015.

***The Long, Long Life of Trees** by Fiona Stafford. Published by Yale University Press. 2016.

***The Norwegian Wood Activity Book** by L. Mytting. Published by MacLehose Press. 2016.

The Real Wood Bible: The Complete Illustrated Guide to Choosing and Using 100 Decorative Woods by Nick Gibbs. Published by Firefly Books. 2016.

The Social Lives of Forests: Past, Present and Future of Woodland Resurgence edited by Susanna B. Hecht, Kathleen D. Morrison and Christine Padoch. Published by University of Chicago Press. 2016.

The Tree by John Fowles and William Fiennes. Published by Little Toller Books. 2016.

The Tree Climber's Guide by Jack Cooke. Published by Harper Collins. 2016.

The Trees of North America: Michaux and Redoutes American Masterpiece by David Allen Sibley. Published by Abbeyville Press. 2016.

The Wood Book by Francesc Zamora. Published by Loft Publications. 2016.

Thirty Years in Wilderness Wood by Chris Yarrow. Published by Matador. 2015.

Treecology: 30 Activities and Observations for Exploring the World of Trees and Forests by Monica Russo (Author) and Kevin Byron (Photographer). Published by Chicago Review Press. 2016.

Trees: A Complete Guide to Their Biology and Structure by Roland Ennos. Published by The National History Museum. 2016.

Trees in Towns and Cities – A History of British Urban Arboriculture by Mark Johnston. Published by Windgather Press. 2015.

Uncommon Ground: A Word-Lover's Guide to the British Landscape by D. Tyler. Published by Guardian Faber Publishing. 2015.

Urban Forests: A Natural History of Trees in the American Cityscape by Dr. Jill Jones. Published by Viking. 2016

Urban Forests: Ecosystems Services and Management by J. Blum. Published by Apple Academic Press. 2016.

***Urban Tree Management** by Andreas Roloff. Published by Wiley-Blackwell. 2016.

Voices of the Forest: A Social History of Scottish Forestry in the Twentieth Century by Mairi Stewart. Published by Birlinn Ltd. 2016.

The Book of Leaves
A Leaf-by-Leaf Guide to Six Hundred of the World's Great Trees

Alan J. Coombes and Zsolt Debreczy

Ivy Press. 2016
656 pages. Hard back. ISBN: 978-1-78240-330-2
£89

This is a beautiful, lavishly illustrated book - at once hugely informative as well as an entertaining read. Despite its extensive coverage of tree species, it is not for use as a hiking guide as it weighs 2.3 kg! The press release accompanying its publication says it all and is difficult to improve on. *The Book of Leaves* offers a visually stunning and scientifically engaging guide to 600 of the most impressive and beautiful leaves from around the world. Each leaf is reproduced here at its actual size in full-colour photographs taken on a lightbox and is accompanied by details of the range, distribution, abundance and habitat of the tree on which it is found, as well as brief scientific and historical accounts." Press releases can often be misleading and convey attributes or compliments for which the publication is not worthy of. In this case every word is true.

A quick perusal of the biographies of the author and editor will illustrate why this volume lives up to such praise.

Following a short "Foreword" and "Introduction" the reader is treated to a 34-page section which sets out the basics of "What is a Tree", "What is a leaf", "Leaf Function", "The Variety of Leaves", "Leaf Shape and Arrangement", "Leaf Anatomy", "Understanding

Plant Names" and "Identifying Tree Leaves". For the non-professional this part of the book is essential reading and leads to a better understanding of the contents of the book. It is also useful as a revision for those professionally involved with trees.

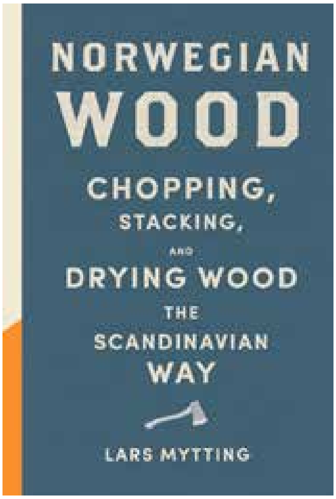
The next approximatively 600 pages are devoted to descriptions of the individual trees using the leaf as the starting point. The material for each species is laid out in a very readable format, including distribution maps, which though small in size are extremely useful. The photographs of the leaves are wonderful (actual size in most cases).

This book deserves to be on the shelves of anybody interested in trees but particularly professionals including foresters, arborists, horticulturists, botanists, teachers etc.

Kevin J. Hutchinson

Norwegian Wood – Chopping, Stacking and Drying Wood the Scandinavian Way

Lars Mytting
MacLehose Press. 2016
191 pages. Hardback. ISBN: 978-0-85705-255-1
£20



It's hard to believe that a book on firewood could end up as Non-Fiction Book of the Year in 2016. It is written by a Norwegian, Lars Mytting, who previously worked as a journalist and non-fiction editor before turning to writing. He shares a Scandinavian passion for wood harvesting, stacking, storing and burning, combining cultural history and folklore with modern science. Entertaining and instructive, *Norwegian Wood* delivers a wealth of advice and technical know-how for the armchair reader and for those outdoors. He provides some fascinating facts, for example Norwegians use 1.5 million tonnes of logs annually. Assuming each log is a foot long and the pile is 6.5 feet high, it would stretch for 4,474 miles i.e. from Oslo to the Congo.

In Norway this book sold over 300,000 copies. It has been translated into ten languages and it is now widely available in most book shops here and in Britain. It was featured on Chris Evans's Breakfast Show on BBC Radio 2 and was BBC Radio 4's Book of the Week. What could have brought about such a degree of enthusiasm for wood chopping? Is it a return to nature or is it a response to climate change? I'm afraid the answer is not to be found in the book, apart from telling us that our relationship to fire is so ancient, so universal, that it seems that in learning about wood, one can also learn about life.

Irish visitors to the Nordic countries and Central Europe marvel at the neat stacks of woods at every house. The author tells us that in the past, single women eyed-up these stacks to see if the man would make a good husband! Lars tells us the late spring is the time to gather and bring in firewood for the following winter. It seems in these very organised societies everybody does the same thing at the same time. Here we tend to be a “just in time” society, oblivious to the damage wet logs do in the long term to our chimneys.

Mytting claims that chopping and stacking wood is a pastime where the world makes sense once more. The book gives us a definitive answer on a topic so often discussed at Irish firesides, namely which timber burns best? He quotes from none other than the Norwegian Forest and Landscape Institute and the following is a list of the top ten in ascending order; beech, oak, ash, elm, rowan, birch, pine, willow, aspen and spruce. He prefers to leave alder for the beavers “to play with”! And who better to impart this wisdom than an expert from Scandinavia, where the extreme climate has obliged generations to hone and share their skills with tools, wood working and heat production. It is not surprising that people who live in cold climates are organised and disciplined because it has been a necessity to ensure survival. People in warmer climates do not have to plan for extremes and with them it’s every-day-as-it-comes. Lars Mytting has distilled the wisdom of enthusiasts, from experienced lifelong growers, stackers and burners, to researchers and professionals of combustion and silviculture.

Part guide to the best practice in every aspect of working with this renewable energy source, part meditation on the human instinct for survival, this definitive handbook on the art of chopping, stacking and drying wood in the Scandinavian way has resonated across the world. There is advice on coppicing, the best species, best axes and best chainsaws -even the best chopping blocks. Needless to say there’s a chapter on stoves with advice on the best Nordic makes and models.

Apparently in 2013 Norwegian Television, obviously prompted by the success of the book, ran 12 hours of programming on various aspects of wood as part of its experiments in “slow television”. They produced a similar television programme with a camera mounted on the front of a train which ran for hours. I just hope the phenomenon doesn’t catch on here!

At the beginning of the book there are some evocative lines from a famous Norwegian poet, who was also a lumberjack.

The scent of fresh wood
is among the last things you will forget
when the veil falls.
The scent of fresh white wood
in the spring sap time:
as though life itself walked by you,
with dew in its hair.
That sweet and naked smell
kneeling woman-soft and blond
in the silence inside you,
using your bones for
a willow flute.
With the hard frost beneath your tongue
you look for the fire to light a word,
and know, mild as southern wind in the mind,
there is still one thing in the world
you can trust.

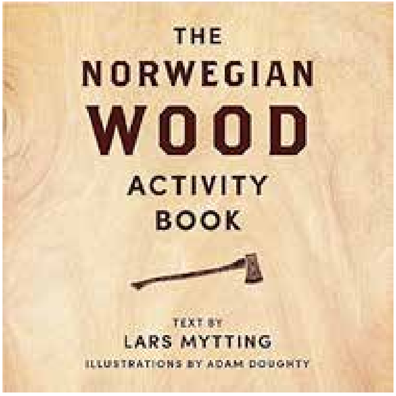
Hans Børli

I think I should leave the last word to Einstein who was alleged to have said "People love chopping wood. In this activity one immediately sees results" and it's hard to disagree with him. Norwegian Wood is the perfect fireside read.

John Mc Loughlin
Business Editor, Society of Irish Foresters &
Chairman, Tree Register of Ireland

The Norwegian Wood Activity Book

Lars Mytting
Quercus Publishing. 2016.
64 pages. Hardback. ISBN: 978-0-85705-657-3.
€11.50



In November 2016, ready in time for the Christmas market and following the extraordinary international success of Norwegian Wood the best-selling manual for chopping, stacking and drying wood the Scandinavian way, this interactive follow-up book offers something for keeping all the family occupied, including:

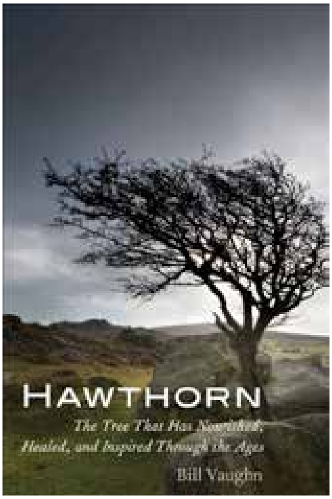
- Top Trunks;
- Spot the difference;
- Dot-to-dot and mazes;
- Cut out and colour the woodchoppers' clothing;
- Step-by-step guides to laying the perfect fire and building a round stack;
- And magnificent frozen landscapes.

This activity book is an original gift and the perfect fireside companion, to bring warmth and entertainment to armchair enthusiasts and active woodcutters alike.

John Mc Loughlin

Hawthorn – The Tree That Has Nourished, Healed and Inspired throughout the Ages

Bill Vaughan
Yale University Press. 2016
272 pages. Paperback. ISBN: 9780300203493
£14.99



As a forester I have taken little interest in the hawthorn apart from admiring its profusion of white flowers at the beginning of summer, especially in the drumlin region. Since my youth I have been aware of the superstitions attached to the cutting-down of a lone hawthorn. Indeed, I recall the late Peter Danaher, Chief Archaeologist in the then OPW, stating that the widely held fear of cutting down or destroying hawthorn bushes saved huge numbers of ring forts from destruction when mechanised land reclamation became prevalent in Ireland. Even in recent years, the route of a major dual carriageway in Co. Clare was altered to avoid a "fairy hawthorn" which stood in the path of the original design. Indeed, it is alleged that the removal of hawthorn to accommodate the DeLorean car factory at Dunmurry near Belfast hastened the demise of the project. Ironically that facility was designed by the firm of Brodie and Hawthorn Architects, Belfast.

Possibly the most surprising thing about this book is that it was written at all. Few would believe that a full 272 pages could be devoted to this single species. In this book the author, Bill Vaughan, has cleverly juxtaposed his family's history in Ireland and in America with the species. His great grandfather, Thomas Moran, was born near Rathgormack, Co. Waterford in 1838. Like many thousands of his contemporaries, he was forced to emigrate to America, where he became the owner of a large farm in the state of Montana which had a profusion of hawthorn. His narrative has a broad embrace which encompasses interesting detail on the Great Famine, the Irish land tenure system and emigration. The book is a hugely original work, which isn't surprising since it was penned by an author who writes for many publications on topics as wide-ranging as sport, the paper industry, fashion and the cattle business.

Bill Vaughan mentions the presence of hawthorn in Europe, America, India, Australia and New Zealand. In his fine book entitled *Trees of Britain and Northern Europe* Alan Mitchell unravels the almost global nature of the species. He explains that our hawthorn is native to Europe and extends as far east as Afghanistan. North America, he tells us, has almost 1,000 species of hawthorn (including one named after the famous plant hunter, David Douglas) and there are 90 species in Europe and Asia. They are generally shrubs but our native species has aspirations to a tree form. The red-flowered varieties of hawthorn, often seen in towns and urban parks, are American varieties and hybrids.

Ireland is rightly famed for its hedgerows; it is estimated that there are 250,000 miles of hedgerows in Ireland with hawthorn being the predominant species. Many of these hedgerows are ancient and some form townland boundaries. However, without continuous maintenance they quickly degenerate becoming ragged and incapable of the purpose for which they were planted, namely to control the movements of large animals and also to keep them sheltered and secure. Many Irish hedgerows are currently in a state of advanced disrepair, but as always with nature, they can be restored with judicious shaping, pruning and layering -a technique that had virtually died out but is now coming back into vogue. Until the arrival of barbed wire, which emulates the thorns of the hawthorn, a living hedge was an agricultural necessity – as essential as a horse and plough.

In northern France, the hedges of Normandy (brocage in French) proved an impenetrable barrier to the Allied forces in 1944 until the Americans developed a blade at the front of tanks that allowed them to drive through them. These hedges are much wider than hedges on these islands as they were originally planted for firewood. They were known as "peasants' forests" and hawthorn became an important element of their understory.

It is said of George Washington, America's first president, that his real ambition was not to lead a great country, but to become a farmer. On his estate at Mount Vernon, Virginia he devoted much of his time to developing hedgerows including the importation of 5,000 saplings of *Cretagus monogyna* from England. Thomas Jefferson also worked on developing hedging on his estate at Monticello, Virginia. However, neither Washington nor Jefferson enjoyed great success with *Cretagus monogyna* because of the persistent summer droughts but it does grow well in other states of the Union.

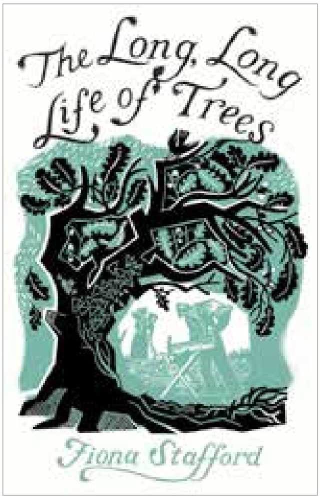
Hawthorn species from Europe were transported across the globe by imperialist nations. The author points out "as the English colonised the world that was new to them, they brought along with them their love of gin, their contempt for the natives, and their diseases". This goes some way to explaining how the European hawthorn ended up in Tasmania where it was used to create hedges. Similarly it was introduced to Australia and New Zealand where it is now regarded as a noxious weed in some parts of these states. In the 19th Century, the British planted 2,500 miles of impenetrable hedge across India and patrolled it with 14,000 enlisted men to ensure collection of the notorious "salt tax". Indeed, this hated tax was not repealed until 1946.

Vaughan's book gives a wonderful insight into a species that has received scant attention heretofore despite its exerting a far reaching impact on the course of history. Just consider the tree, which was once an icon of paganism, but later became an object of veneration by Christianity as it sought to eclipse the "old" religion. This tree is a mass of paradoxes, perhaps best illustrated by the old Irish saying "when all fruits fail, welcome haw".

John Mc Loughlin

The Long, Long Life of Trees

Fiona Stafford
Yale University Press. 2016
287 pages. Hardback. ISBN: 978-0-300-20733-0
£16.99



In this volume, with 60 black and white illustrations, Fiona Stafford offers intimate, detailed explorations of seventeen common trees from ash and apple to pine, oak, cypress and willow. It is not just about the bucolic aspects of trees but it discusses past and present practical uses of wood, tree diseases and the environmental threats. She discusses trees' potential contributions toward slowing global climate change.

The book is a personal commentary of the author's love and appreciation of trees, coupled with fascinating examples of how trees have featured in history, art, commerce, culture and folklore. The author, Fiona Stafford is professor of English at the University of Oxford where she teaches literature. She is the author and presenter of the highly acclaimed *The Meaning of Trees* for BBC Radio 3's The Essay.

She creates a delightful palimpsest with poets, prose writers and painters and she includes quotes from Coleridge, Dante, Robert Frost, Thomas Gray, Seamus Heaney, Thomas Hardy, Gerard Manley Hopkins, Shelly, Tennyson, and Sylvia Plath among others. She introduces painters too into her narrative with Cezanne, van Gogh and Monet. Liberal references from the Greek and Roman legends also abound in the work.

In her chapter on cypress she discusses the problem in Britain with Leyland cypress and how it has caused neighbours to fight and end-up in court. She illustrates this with an example of the behaviour of a Lincolnshire pensioner who decided to deal with his neighbour's bushy row of Leylands by secretly relieving himself underneath at night time. It was a slow, rather smelly death and would have been the perfect murder if only it hadn't been caught on camera! Unfortunately she doesn't say what happened next!

From her chapter on oak I learned that it is the national tree of Britain, as it is here. What I didn't know is that it is also the national tree of Bulgaria, Croatia, Cyprus, Estonia, France, Germany, Latvia, Lithuania, Moldova, Poland, Romania, Serbia and the USA ….. and we thought we were being original!

In her chapter on ash she quotes from the great botanist Oliver Rackham who in his last book, completed before his death in 2014, said "he casts a cold eye over the panic reports of the likely effects of ash dieback, observing that by the time people have noticed the presence of the deadly plant disease it is too late to take action; the latest year to react to Chalara was 1995". In an effort to cheer us up we learn that the next threat is likely to be the emerald ash borer beetle which has already devastated ash across the US and Siberia. In an era of globalisation, its arrival here is almost unavoidable. Hurling fans will be bemused to find that there is not a single reference to the cumán in the entire chapter!

In the chapter on apples her knowledge of pomology is astounding and in the poplar chapter she tells us that in 2006 the Californian poplar *Populus trichocarpa* was the first tree to have its entire DNA mapped, which will provide information about the gene structure of trees leading to more practical experiments on tree breeding.

On the holly she has a nice piece on the misnaming of different varieties, "Golden Queen" and "Silver Queen" are male whereas "Golden King" and "Silver Milkboy" are female. She reminds us that mature hollys do not take well to transplanting and she points out that hollys are happiest when they have space to grow outwards.

On the chapter on sycamore, which may well be a replacement for ash, she sings the praises of the species which has suffered a bad press, with gardeners often accusing the tree of being a profusion of too much sap and too many leaves. At every turn the rude health and vigour of this species seems to count against it!

On the chapter on birch she says that its therapeutic benefits are enjoying a revival. Even as far back as John Evelyn's time when he praises a birch concoction (pardon the expression) as "a great opener" and recommended it for pulmonary complaints and piles.

On the horse chestnut she tells a very poignant tale from Ann Frank's diary, about how she wrote of the greenness of the leaves and the presence of the flowers of a particular tree and then within three months, the Frank family were betrayed to the Nazis and died in Bergen-Belsen only weeks before the war ended. That chestnut became a shrine, but in 2007 the city fathers in Amsterdam decided to issue a felling notice. There was such a public outcry that it got a reprieve and remedial action was taken, however it succumbed to a severe gale in 2010 and cuttings of the Ann Frank chestnut have gone all over the world. The horse chestnut is another species heading for trouble with a plethora of diseases and insects threatening on the horizon.

In the pine chapter she deals with our fear of dark woods, when young we had tales of *Hansel and Gretel*, *Little Red Riding Hood* and *Beauty and the Beast*. Vast pine forests feature in many of these tales and even though the story ends happily, it leaves a dim sense of some terrible menace lurking within the evergreens. Add to this concoction the presence of bears and wolves and it's easy to understand how people seem to fear conifer plantations.

There are niggly mistakes in the text, like craoibh, which she says is the Irish for tree, it is of course the Irish for a branch of a tree. The Irish for tree is *crann*, a quick Google-translate would have sorted that out. Nor will the Icelandic Forestry Service be too pleased when she says "Inspired by old Norse literature, I travelled to Iceland and found not a single tree in the entire country". She has a reference to Tim Robinson's account of Connemara but there is no sign of the source in the reference list.

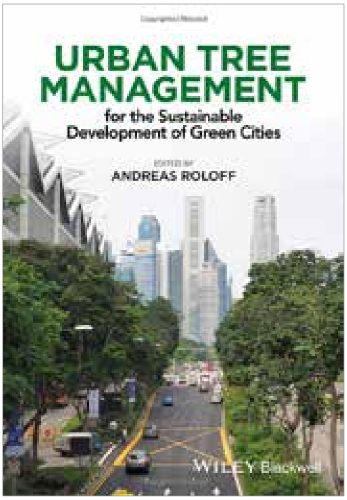
Her reference list for Ireland is very sparse on woodland literature although there are literary references. However, she does manage one gem, apparently a royal medal was struck with Oliver Cromwell on one side and an olive branch on the other and she comments "for many in Ireland Cromwell's olive branch seemed grotesquely distorted"!

Overall this book has a very different and erudite way of looking at the trees that we come across every day and is a charming read.

John Mc Loughlin

Urban Tree Management for the Sustainable Development of Green Cities

Edited by Andreas Roloff
Wiley Blackwell. 2016
274 pages. Paperback. ISBN: 978-1-118-95458-4
£45



This book is edited by Andreas Roloff, Chair of Forest Botany, Dresden University of Technology, but contains contributions by 15 other (all German) professionals. It is an ambitious book in that it attempts to cover all aspects of urban tree management. In that context and for those readers who may contemplate purchasing this book, it is worth listing these chapters. They are as follows:

1. Intro: Urban Trees – Importance, benefits, problems.
2. Urban Trees: Features and requirements.
3. Fundamentals of tree biology for urban trees.
4. Urban tree roots: Problems and peculiarities.
5. Drought stress: Adaption strategies.
6. Aspects of urban tree pathology.
7. Vitality assessment, tree architecture.
8. Body language of trees, tree diagnostics.

9. Tree inventory, risk assessment and management.
10. Tree preservation, maintenance and repair.
11. Tree pruning: Methods and parameters.
12. Transplanting large trees.
13. Dust and noise reduction.
14. Invasive species, indigenous vs. alien dendroflora.
15. Criteria for species selection: Development of a database for urban trees.
16. Genetic aspects.
17. Governance in urban forestry.
18. Allotment gardens and privately managed green space in urban environment.
19. Urban woods for relaxation and inspiration.
20. Acceptance for urban trees: Environmental education programmes.

Urban tree management is going to be fundamental to ensure that the cities of the future can be green ones. *Urban Tree Management* aims to raise awareness of the positive impacts and benefits of city trees and for their importance to city dwellers. It describes their advantages and describes their effects on the quality of urban life and well-being? In an age of increasing world-wide urbanisation, such aspects are becoming ever more important than ever before.

Does this book live up to its ambitious contents? In general it does and the list of references, particularly the many in English for this audience are very useful sources for further reading. With such broad coverage, not all subjects get extensive, highly detailed treatment, however, there is sufficient material to provide a solid foundation for each area discussed. Given that the editor and all the contributors all live and work in Germany, it is not surprising that the source material is all European.

This book is also extremely well illustrated with colour photographs and diagrams.

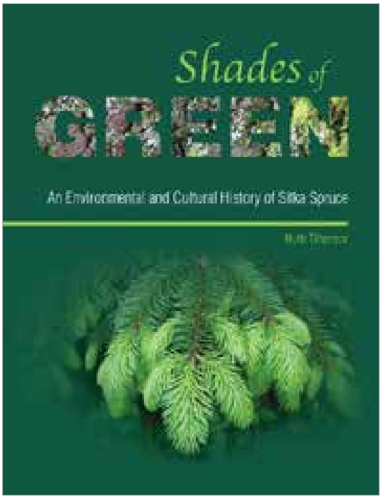
Anybody interested in or working with urban trees (the book is aimed at a wide variety of professions like arborists and arboriculturists, horticulturists, plant scientists, forestry scientists, city planners, parks department specialists and landscape architects) will find the book extremely useful, but may want to supplement it with books specialising in the many subjects covered in the 20 chapters.

Overall this is a very good book, an excellent general treatment of the subject, and is recommended to readers.

Kevin Hutchinson

Shades of Green
An Environmental and Cultural History of Sitka Spruce

Ruth Tittensor
Windgather Press (an imprint of Oxbow Books),
London. 2016
375 pages. Paperback. ISBN 978-1-909686-77-9
£29.95



When I saw the words "Sitka spruce" and "environmental" in the title of this book I feared for the worst; neither was I encouraged by the opening sentence on its dust cover which read – "This book takes a look at the most disliked tree in Britain and Ireland". However, having finished the book, I feel that Ruth Tittensor, who read botany at Oxford and woodland ecology and history at Edinburgh, has done a remarkable job in refuting much of the ill-informed and misguided comment about this species which one commonly encounters.

She begins by discussing its importance in the coastal region of Western North America and explains its significance for First Nation peoples who view Sitka spruce quite differently from Europeans. They prize it for its beauty, its spiritual significance and for the many items it supplies them –e.g. canoes, woven bowls, glue etc.

There are many gems of information between these covers – perhaps the most surprising is that there are now more Sitka spruce trees in Britain and Ireland than in its natural range which extends from California to Alaska -a narrow belt rarely more than 80 km wide (Figure 1). Since the late nineteenth century it has been the most important timber tree for the timber industry of west coast North America. Sitka is the tallest of the spruce species and comes number three worldwide after coast redwood and Douglas fir.

The conservation emphasis on the native and the natural has caused ecological research on conifer plantations to be neglected. It is therefore frequently assumed that modern, planted forests are much poorer in associated species and ecological dynamics than native woodlands. She concluded that years of complaints about Sitka spruce afforestation displayed little understanding of the fact that it was an industry which provided us with everyday items under extremely difficult ecological and working conditions. Although greater numbers of urban dwellers visit forests now, the link between a working countryside and goods produced appears to be tenuous. Few realise that their newspapers, kitchen units, even the walls and roofs of their houses might be made of Sitka spruce.

Ecologists, conservationists and foresters assumed that conifer plantations supported few flora and fauna – plants and animals could not easily be seen, therefore they were absent. They also assumed that conifer plantations needed "improving" for biodiversity and looked at ways of "improving" Sitka spruce forests for nature conservation. But they provided no data to show that these forests actually needed improving. Foresters responded to these criticisms but had no baseline against which to check their "improvements". Compared with ecological studies of broadleaved woodlands, projects and publications about plantations of introduced conifers are negligible. Yet Sitka spruce is the commonest tree in Britain and Ireland! Our understanding of conifer plantations is scant; it lags a century behind our understanding of deciduous forests. However, the important ecological work undertaken by UCC in recent years is completely absent from the text and references. This serious oversight is disappointing as the UCC work clearly demonstrates that under Irish conditions there is much greater biodiversity in Sitka spruce forests than heretofore believed.

Ruth Tittensor says "that there is no longer any need [was there ever?] to compare Sitka spruce plantations unfavourably with other woodlands." She suggests "that we put away our nostalgic, rose-tinted daydreams of the *ideal* Sitka forest". Instead, we should look ahead and discover, without prejudice, just how they evolve. She suggests we also finish with the dogma of "naturalness" which has forced organisations and individuals to try merging (native, natural woodlands) into one identity with (Sitka spruce look-alike native natural woodlands) – instead we should let them develop ecologically without pre-conditions.

Her book alerts us to the imminent dangers posed by climate change. In Britain, the growing season for Sitka spruce already begins three weeks earlier than it did 60 years ago. While Britain and Ireland will continue to be oceanic, except possibly in the south east, Ireland is fortunate in that the John F. Kennedy Arboretum is located in the south east and data have been collected there since the arboretum was established in 1968. Analysis of these data will help to formulate a policy on which tree, or trees, might replace Sitka spruce.

The palate of species could include Macedonian pine (*Pinus peuce* Griseb.), Douglas fir (*Pseudotsuga menziesii* (Mirb.) Franco), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) and Chilean pine (Monkey puzzle; *Araucaria araucana* (Molina) K. Koch). She concluded that the apparently featureless and wildlife-deficient Sitka spruce plantations are gradually developing recognisable ecological features. Sitka has the potential to form temperate rainforests this century as well as producing much-needed goods for society. But conserving natural old-growth forests, sustaining the needs of First Nation peoples, and producing materials for the modern timber industry will be an intricate balancing act.

The author lists all the local names for Sitka spruce which are found throughout the world. She includes Gaelic, and even Canadian Gaelic, which is given as *craobh spruisead,* which actually translates as a spruce branch. That apart, the author succeeds admirably in getting the balance right between our two islands as there are minor climatic differences but major cultural and attitudinal differences towards Sitka spruce.

In spite of these, this is a timely publication and one that should be read by anyone interested in the countryside, be they conservationists, foresters, landowners and planners. It is a must for every forester's Christmas list. Perhaps we should leave the last word to the Alaskan ecologist, Richard Carstensen, who says "In Alaska we almost worship it".

John Mc Loughlin

Figure 1: *This impressive specimen was felled in Sitka National Park as it had become a danger to the public. Reproduced with kind permission of Oxbow Books.*

Heritage Irish Plants
Plandai Oidreachta

Brendan Sayers and Paddy Tobin (Eds.)
Irish Society of Botanical Artists and Irish Garden Plant Society. 2016
Pages. Card bound. ISBN: 978-0-9928693-1-1
€25

Readers may muse that a review of a book such as this is not for *Irish Forestry*. However, though not a book about trees or forestry, it is, nevertheless a worthy candidate for anyone with an interest in the finer botanical details of Irish garden plants or their conservation.

As its title suggests this books deals with what is termed *Heritage Plants*. Paddy Tobin in his introduction talks of "plants bred, raised or which happily occurred here in Ireland" as the subject matter of the book.

There are eight articles written by different authors and fifty eight artists provide the accompanying illustrations. While the articles are well written and very informative, it is the botanical art which sets this book apart. To say that most of the illustrations are exquisite is an understatement. The variety of plants illustrated is complimented by the varying styles and artistic skill of the artists. Readers of *Irish Forestry* will also be interested to see the inclusion of a number of woody species.

This publication is further enhanced by the quality of the paper used and the superb printing which occurred in Ireland.

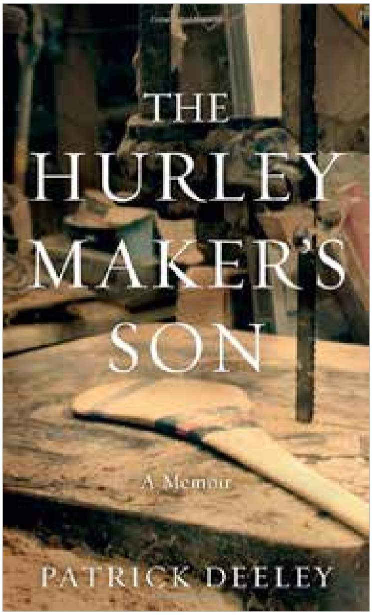
Buy this book. You won't be disappointed!

Note: *this book was launched on 12th November 2016 and as a consequence the opportunity for reviewing has been short.*

Kevin Hutchinson

The Hurley Maker's Son: A Memoir

Patrick Deeley, 2016
Doubleday Ireland and Penguin Random House UK
253 pages. Hardbound. ISBN: 9781781620335
Softbound. ISBN: 9781781620373
Recommended prices: £20.99 (hardbound)
£12.99 (softbound)



Patrick Deeley is not the first author to try and make sense of a life that begins in an idyllic but at times harsh environment and ends in the inevitable leaving of place, family, friends and innocence. However, his journey from rural childhood and adolescence to urban adulthood has a number of ingredients that mark it apart from other memoirs exploring similar themes and terrain.

Life on a small farm in the townland of Foxhall, east of Loughrea, Co. Galway in the 1950s and 1970s is vividly captured by Deeley but it's the allure of the woodland that shapes his father's, and ultimately, the author's life. Like many small farmers, his father Larry had to work outside the farm to subvent the family income and his road less travelled led him to hurley making and carpentry.

But Larry Deeley is more than a hurley maker. Unlike most hurley makers who source the raw material, now invariably harvested in European forests, Larry lives and breathes hurley ash from tree selection and harvesting in the forest to the sawing, planing, shaping and sanding in the sawmill and workshop. He is at one with his craft, from start to finish.

Patrick Deeley describes the sights, sounds and smells of this cycle of events as it unfolds each time his father wins a contract from the Forest and Wildlife Service to purchase a stand of ash. The main actors, led by the hurley maker himself, swing into action with their machinery, muscle and occasional mayhem. The strolling players include the author's uncles, brothers and a near neighbour, the menacing Paddy Joe McHugh–aka "Strong"– who provides devilment and muscle.

They act out their roles in the woodland, sawmill and workshop, but we learn in the opening chapter of *The Hurley Maker's Son* that the curtain has come down for Larry Deeley in his final tragic act. The author is on the Dublin to Galway train ruefully reflecting on a note**,** dropped in to his Terenure bedsit**,** which urges him to return home as his father has had an accident. Well aware of the inherent dangers in felling ash trees, he fears the worst.

He learns the circumstances of his father's death from his brothers Simon and Vincent. Over familiarity with his work, coupled with pressure to get the job done, led him to take an uncharacteristic risk when cutting through a felled tree to free it. But "the upper section of the tree lurched, striking him on the left temple before he could step back". This all took place in an era before health and safety; before helmets became mandatory not just for the hurley ash harvesters, but also for the hurlers who wielded the finished camáns.

He also learned from his brothers that it was a week when nothing seemed to go right. The hurley maker's wife Mary "the chief farmer in the family" reminded him that the barley was overripe and should take precedence over the hurleys. But the rains came so they headed for the wood at Moore near Athlone where chainsaws gave trouble and felling was difficult. The hurley maker liked open well-thinned woodlands but, "the trees at Moore were rooted close to one another and in their reach for light, they had grown unusually tall."

His father was conscious of the continuum in good forestry practice. The author portrays him as a craftsman and forester conscious of sustainable forestry long before the term was coined. We learn this in the poetry of Deeley's *Groundswell: New and Selected Poems*. In "Woodman" he describes his father at work, carefully selecting the right ash trees for hurley making while keeping an eye on what is left behind, for future selection.

> And he satisfied himself he was leaving at least a dozen trees for
> each tree he felled.
>
> The years of his apprenticeship sprouted afresh at Woodlawn as
> dusk silenced work...

His father passes on his knowledge of wood to Patrick and his siblings, mainly through work but he also took time to explain the characteristics of different timbers

> He explained that wood is made of fibres and these are perforated with many tiny pores through which it breathes and sweats. In fact we could smell the sweating and breathing wood around us. 'Ash has hardly any smell,' he continued, 'and oak is generally mild, though it can be sour as cat's piss. Larch holds a small whiff, but the tar-and-turpentine smell of the lovely Scots pine – aah, that's the dominant one.'

While the woodland and its associated crafts are central to the book's narrative flow, the landscape of the Foxhall Callows acts as a spiritual and topographical counterpoint. Unlike the forest, it is wetland and virtually tree-less, but its flora and fauna exert a strong hold on the young Deeley even when his ill-tempered school teacher dismisses the local callows as "a miserable bit of old marshy ground" compared to the River Shannon Callows.

The death of his father releases a rich set of emotions in Deeley as he retraces his formative years spanning his primary school experiences followed by secondary school in St. Brendan's, Loughrea. Young Deeley was bright and in today's environment would be regarded as an exemplary student. But in the overly strict school environment of the 1960s and early 1970s, he was regarded as troublesome at times, when even the slightest misdemeanour was punished.

Career opportunities were limited when Deeley left school. He acknowledges that he didn't have the required skills for carpentry and hurley making and had no desire to enter Tynagh Mines, which was then a major but unsustainable employer in the area.

Various experiences during his youth pointed towards teaching and in 1973 he was accepted by St. Patrick's Training College in Drumcondra, Dublin. He began his teaching career in De La Salle National School, Ballyfermot where he was eventually appointed principal. Deeley also began to cut it as a poet, mixing it with writers such as John F. Deane, Pat McCabe, Gabriel Rosenstock, Conleth Ellis and John Ennis.

While much of the book revolves around his father, other male relatives and friends, Deeley was fortunate in having two strong women by his side. His practical mother saw the potential in him and insisted that he would "receive a secondary education irrespective of the costs involved". Judy Carroll, his girlfriend and later his wife, encouraged his writing and persuaded him to send his first poems to the visionary David Marcus, editor of "New Irish Writing" in the now defunct *Irish Press*.

This book is part celebration and part lament for a way of life which is rapidly fading from the rural landscape. Even the very ash trees that features throughout are now under threat as the deadly ash dieback disease – caused by the fungal pathogen

Hymenoscyphus fraxineus – casts its silent deathly shadow over the ash woodlands and hedgerows of Ireland and the rest of Europe.

Near the end of *The Hurley Maker's Son*, Deeley stands "in the derelict yard of his childhood" where he finally comes to terms with his father's tragic death:

> I saw that the tragedy had come almost in the nature of a gift from him to me – of another life, an alternative to his. I accepted the gift that still came, and the fact of his death.

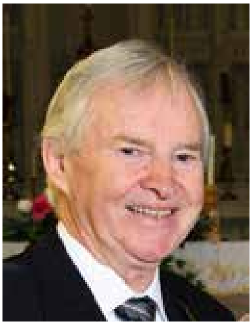
The author wanted "his life back, but writing poems about it was as close as I could get," he says. Which is why poetry matters, especially when a life is thrown off kilter. The memory of his father and the land of his father lives on in Deeley's poetry, and now it has been recaptured in prose with dignity, poignancy and humour in this accomplished bitter-sweet memoir.

Donal Magner
Wicklow

Donal Magner is forestry editor of the *Irish Farmers Journal,* secretary of the Wood Marketing Federation and author of *Stopping by Woods: A Guide to the Forest and Woodlands of Ireland*.

Obituaries

Patrick Kevin (Pat) McLoughlin
1946-2015



Pat McLoughlin passed away on 15th November 2015 after a long illness borne with great courage. Throughout he relied on his hallmark good humour to minimise the very serious difficulties that he was enduring: "I'm grand out thanks, but I'm very busy going for check-ups!" was his usual response.

Pat was born on 6th September 1946 in Westport, Co. Mayo to Edward and Maureen (née Davitt). His father, who worked for CIE, was transferred to Dublin when Pat was three years of age and he began his schooling there. Unfortunately, he was unimpressed with his first visit to school and decided not to attend again!

Pat's family moved house several times over the course of his father's career. After Dublin their next move was to Tralee and, in spite of spending only one year here, he developed a huge admiration for the skills of Kerry football. At an early age, Pat was introduced to these skills while playing football on the street with neighbouring children. The next move was to Newport, Co. Mayo, the birthplace of Pat's parents, where they remained until he was ten. Their final transfer was to Claremorris where Pat spent the remainder of his life.

Pat attended St. Colman's Secondary School in Claremorris. He was a keen footballer at school and also with his local club, Garrymore, where he was a member of the team which won the Mayo Intermediate Championship. In 1965 he began his studies in UCG where he also played football. However, as it was not permissible in those days to play for the College and his own club simultaneously, Pat opted to continue playing for Garrymore. However, injury brought his footballing career to a premature end whereupon the club appointed him manager of their senior team. He was extremely successful in this role and under his leadership Garrymore won the Mayo County Championship, the Connaught Championship and were narrowly beaten in the All-Ireland Club Championship Final.

After two years studying Agricultural Science in UCG, Pat decided to specialise in forestry so he transferred to UCD in 1968 as UCG did not provide forestry as an option. His heart however, was always in Mayo and he invariably returned home to Claremorris every weekend to his family and to his beloved girlfriend, and later wife, Bridie. Such were the attractions of Mayo for Pat that these weekends were often a little longer than the Professor of Forestry might have wished. However, Pat did spend two very enjoyable and successful years in UCD, graduating in 1970 with an honours degree.

He began working in the Forest and Wildlife Service in 1970. His outgoing personality made him a natural for work in land acquisition and he remained in this area until 1983, serving in Limerick, Sligo and finally ending up back in his beloved Mayo. With his twinkling eyes, his charm and above all his innate empathy for people and concern for their welfare, he could usually find a way through seemingly insuperable problems: "Listen, sure I'll make you a little offer anyway, and who knows you might be tempted or you might not".

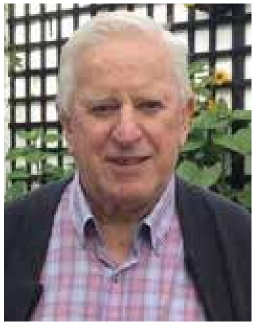
In 1983, Pat transferred to forest management when he was appointed District Inspector in the Castlebar area and later Acting Region Manager in Galway. In both of these roles he was very successful. He had a particular interest in the quality of the end product and the need for improved timber production standards, all aimed at widening the use of Irish timber in the construction sector. Many of his former colleagues remember the many forceful presentations he made on this subject at Coillte's annual conferences.

Pat was above all a family man. In spite of suffering poor health in recent years he loved pottering about fixing things in the house and most of all loved the company of his grandchildren and in the words of Bridie, his wife, "loved annoying them with daft chat".

To Bridie, his children Pat, Anne, Claire, Marian, Eddie and Treasa, his grandchildren, and all his family we extend our deepest sympathy.

Dermot O'Brien and Paul Clinch

Patrick Joseph (P.J.) Morrissey
1928-2015



Much to the sorrow of his family, former colleagues and many friends, P.J. Morrissey passed away peacefully at his home in Castlepollard on 16th December 2015 in his 88th year.

Always known as P.J., he was born on 7th March 1928 at Rathgormack, Co. Waterford to Patrick and Margaret [née Power], the third child in a family of five. He received his primary education at Rathgormack National School and his secondary education at the CBS in Carrick-on-Suir.

His forestry career began in Avondale on 15th January 1947. He completed his training there in September 1949 and was assigned, as Forester Grade 3, to Slievenamon Forest. He was later moved to Callan and Banteer Forests and in April 1951 he was transferred to Co. Donegal. His first assignment in Donegal was to Stranorlar Forest and in 1952 he was transferred to Meeniroy Forest.

P.J. was promoted to Forester Grade 2 on 20th July 1956 when he became forester-in charge at Avoca Forest. In 1959 he took charge of the combined forests of Virginia and Castlepollard.

He was promoted to Senior Forester in August 1971 and was assigned to Clogheen Forest. He returned to Castlepollard in October 1973, following the upgrading of that forest to senior forester level and here he remained until his retirement on 7th March 1993.

P.J. was a highly respected and knowledgeable forester who insisted that everything he did was to the highest standard. His interpersonal skills matched, in every way, his forestry skills. His extensive knowledge of broadleaf silviculture was acquired from decades of "hands on" experience managing, what is reputed to be the largest beech plantation in Europe at Mullaghmeen, Castlepollard.

He had an outgoing and engaging personality, was a great story teller and kept his audience spellbound. Although many may have questioned the veracity of some of his stories and adventures, they liked "the way he told them". Above all he was wonderful company. P.J. was deeply involved in local community affairs. He was a founder member of Castlepollard Credit Union and served on its management board in various capacities over a 40-year period.

He was an active member of his local Gun Club which provided a guard of honour at his funeral. He also participated in a number of other local initiatives such as the Tidy Towns Committee and was a member of the Bridge Club and the Motor Cycle Club in nearby Fore.

His much admired garden was a source of great pride to him. The broad range of vegetables and flowers that flourished there was a testament to his horticulural skills, while his brightly coloured beehives and their contented bees added colour and diversity to his home environment. As if he was not already fully occupied, he saved his own turf - no doubt a project influenced by Rose, his Donegal born wife. Horse racing too was a pastime he enjoyed and he was a regular attender at the Kilbeggan, Mullingar and Navan race tracks.

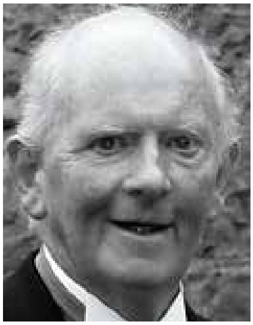
A loyal and regular attender at our field-days, he took part in more than a dozen study tours in Ireland and abroad. His last study tour was to Croatia in 2009.

We offer our sincere sympathy to his wife Rose (neé McMenamin) from Ballybofey, Co. Donegal. They were married in August 1956 and sadly he did not live to celebrate their diamond wedding anniverary. To his children Margaret, Mary, Patrick, Catherine, John, Geoffrey, Daniel and Niall we offer our sympathy. May they take comfort from the high esteem his colleagues hold for their father and the joyous memories he left for us all.

"Ar dheis Dé go raibh a anam dílis."

John Conneff

Joe Doyle
1938-2016



The unexpected death of Joe Doyle on 4th January 2016 at the Mater Private Hospital in Dublin came as a great surprise to everyone in forestry.

Joe was born in London on 26th November 1938 to Kieran Doyle, who hailed from Clogheen, Co. Tipperary and Margaret (née O'Grady) who was from nearby Thurles, Co. Tipperary. He was the second oldest of four children. His siblings Eileen, Philip and Joan lived in England for their adult lives. His youngest sister Joan passed away in May 2016.

Before the outbreak of the Second World War the family returned home to the more peaceful surroundings of Shanrahan near Clogheen in the foothills of the Knockmealdown Mountains, where Joe was raised and attended the local national school. Joe received his secondary education at St. Joseph's College, Cahir.

It was somewhat inevitable that Joe would end up choosing forestry as a career making it the third generation of his family to work in that industry. His father Kieran, as well as farming part time, was a leading worker in the old Clogheen Forest and his father Joseph, Joe's grandfather, was also a forest worker in the Clogheen area. The Doyle family have been living in this area since the 1700s.

Joe began his forestry career in 1957 at Kinnitty Castle, Co. Offaly and completed his training in 1960 at Shelton Abbey, Co. Wicklow.

His first assignment, in 1960, was as an Assistant Forester to Roscarbery Forest, Co. Cork. He spent two years there before spending a further two years as a housemaster in Kinnitty Castle Forestry College. From 1964 to 1970 Joe worked in the following forests; Foxford, Co. Mayo for one year and then Ballyhoura, Co. Cork for two years. He was then promoted as Forester-in-Charge and was assigned to Doolough and Maam Forests. While working in Co. Mayo Joe met his future wife, Anne Devanney from Lahardane, and they married in March 1967. Joe and Anne had three sons, Kieran, Declan and Conor.

In 1970 Joe was transferred to Comeragh Forest, Co. Waterford and he lived in Dungarvan for 11 years until 1981 when he was promoted as Assistant District Inspector in Castlebar, Co. Mayo. Following the establishment of Coillte in 1989 Joe was promoted again and worked as District Manager of the North Mayo District until 1991. He transferred to the new Forest Service in 1991 as District Inspector of the Galway District and later of the Mayo District. He remained in Castlebar until he retired in November 2003. While he was a proud Tipperary man at heart, Joe also valued his long association with Mayo and Galway.

Joe had a huge interest in forestry and carried a wealth of knowledge and experience which he shared generously with his colleagues and peers. He was diligent in keeping well informed of new developments and on-going research. He spent the years, up to his untimely passing, as a part time forestry consultant. This epitomised Joe's interest in the forestry career which he loved.

Joe took a keen interest in the Society's activities and he was very helpful in arranging the Society's 60th Anniversary Tour of the West of Ireland in 2002. He participated in many field days and study tours at home and abroad.

Joe Doyle was one of life's gentlemen. His wit and good nature earned him the friendship and respect of all who were his colleagues and clients. He had a great sense of humour and possessed a witty turn of phrase. While doing an introductory speech during an EU Forest Service Audit he once described his adopted county Mayo as "*the land of peats, peaks and piety*". His colleagues remember him at union meetings speaking gently from the floor with a wry smile suggesting that the union should not forget to "*look after the old and the cold*".

He was a deeply religious man and many of his journeys with Anne to the United States and throughout Europe included regular visits to the famous Marian shrines. He had a great interest in Gaelic games, particularly hurling and was involved over the years at grass-roots level at his local clubs.

Joe's funeral to Creagh cemetery followed mass at the adjoining Our Lady of Lourdes Church in Ballinasloe. It was a fitting testament to Joe's life and personality that the wake and funeral drew a large attendance from far and wide. His son Kieran delivered a particularly apt oration at the mass and "Slievenamon" was played at the graveside.

We offer our sincere sympathy to his loving wife Anne, sons Kieran, Declan and Conor, to his brother Philip and sister Eileen.

Noel Foley

Peter Alley
1941-2016

Peter Alley, one of Ireland's best known foresters and nurserymen, passed away peacefully on 6th February 2016 at the Hermitage Medical Clinic, Dublin following a long illness which, as one would expect of the man, he bore bravely.

Peter was born in Durrow, Co. Laois on 10th April 1941 to John Alley and Cathy (née Lacey). He was educated at Durrow National School, St Kieran's College, Kilkenny and the Patrician College, Ballyfin, Co. Laois.

He began his forestry career in November 1959 at Kinnitty Castle Forestry College in Co. Offaly and completed his training at Shelton Abbey, Co. Wicklow in August 1962. On completion of his forestry studies, he was appointed forester at Ossory Forest, Co. Laois. Subsequently he was transferred to Bandon Forest, Co. Cork and from there he was transferred to Research Branch with headquarters in Mountrath, Co. Laois. After this, he spent short periods in Portlaoise and Urlingford Forests before been transferred to Ox Mountain Forest, Co. Sligo in February 1970 as a forester-in-charge. In August 1973 Peter moved again to take up the post of sawmill manager at Dundrum Sawmill, Co. Tipperary. This was his last cross country move. His final post before retiring was as forester-in-charge at the adjacent Hollyford Forest where he was based for three years.

In January 1988 Peter made his break and retired from the Forest Service. Once free of the shackles he threw himself, with typical gusto, into the development of the first class Dundrum Nurseries together with a forestry company, Forestry Services Ltd, with its two subsidiary companies – Sár Caman Teo and Red Squirrel Forestry Services which between them provided a complete service for landowners.

Peter will be remembered by a generation of foresters as a tenacious union official. During the 1960s, the foresters' terms and conditions of employment were poor; their pay was low relative to similar Civil Service grades, the grading structure had become dysfunctional leading to very limited promotional opportunities, the forester transfer system was unfair, illogical and frequently perceived as vindictive, official housing was inadequate and did not meet the needs of married foresters and their families.

The State Foresters Association (SFA) carefully managed the pent-up anger and frustration of its membership and in time a younger cohort of members was elected onto its Executive Committee. Peter waded into this battleground with great passion and fire. He was sharp, skilful and radical, a fiery orator and a dogged and tenacious negotiator who took few prisoners at the table. The negotiation table was the scene of many lively battles between the official side (Forest Service) and the SFA. However, in due course, wise counsel prevailed and the long awaited 1972 Agreement was finalised and signed by both parties.

This agreement introduced a revised grading structure which provided more promotional opportunities and better pay for foresters and the annual intake of forestry trainees was reduced. Most importantly, the dreaded "transfer system" was replaced by an application process for newly created and existing vacant posts. Foresters could now purchase or build a house in a location of their choice. Peter Alley had many significant achievements in his lifetime but his work for the State Foresters Association is hugely appreciated by foresters of his generation.

There was another interesting side to Peter's life. He was the producer of several acclaimed "Musicals' - which he referred to as "the joy of his life". He began with the local church choir, progressed to annual "Pantomimes" and finally, graduated to the "Musicals". His first production was *My Fair Lady* and this was followed in quick succession by *Oklahoma, Oliver, South Pacific* and *Carousel*. These, and many more, were organised by Peter and the members of St. Oliver's Musical Society between 1976 and 1984. However, Peter enjoyed one final hooray when, in 2010, he produced an open-air *Oklahoma* for the parish of Boherlahan Dualla in the local GAA field. It was a resounding success which is still talked about in the locality.

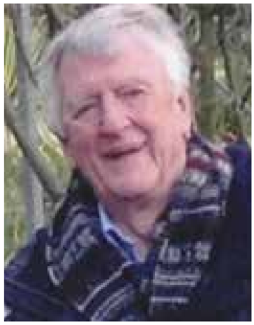
In his later years, despite his long battle with ill health, Peter found the time and energy to write a book entitled *My Way* which was published in 2013. It is a compelling read, which recounts the story of this versatile man of many parts who left a lasting legacy wherever he went.

To his wife Josie, whom he describes in the book as his goalkeeper, full-back, midfielder and attacking forward line, and to his children Sean, Frank, Siobhan, Bobby, Gráinne, Ray and Marguerite, we offer our sincere sympathy.

Thanks for the memories Pete.

John Moore

Fredrick J. (Freddie) Shekleton
1940-2016



Freddie Shekleton passed away peacefully in his sleep on 31st March 2016 in his 77th year, at home with his beloved wife Elizabeth at his side.

Freddie was born in Ferns, Co. Wexford on 8th March 1940, the elder of two boys to Edward from Co. Cavan and Margaret (Née Copeland) from Co. Wexford. His only sibling Robin, predeceased him in 2011.

The Shekleton family moved to Dublin in 1944 where they purchased the house in which Freddie lived most of his life and where he died. He attended primary school at Kingstown School, Dún Laoghaire and continued his education at Avoca Secondary School, Blackrock. After completing his secondary education he enrolled at Trinity College Dublin to read forestry. Having completed two years study there, he transferred to University College Dublin to complete his degree in forestry. During this period he completed his practical work at Killakee Forest. In later years Freddie often spoke of the educational benefits and the very enjoyable time he spent there with the late Mairtín Ó Neachtáin. Freddie graduated with a degree in forestry in 1966.

In 1967, like most people qualified in forestry at that time, he joined the Forestry Division of the then Department of Lands. His first appointment was to Research Branch and he was assigned to the JFK Arboretum near New Ross, Co. Wexford. Together with the late Tony Hanan, he was involved in the planning and establishment of what is today a world class arboretum. In 1969 he married Elizabeth Brady from Sandymount and in the same year, due to the untimely death of his father, Freddie left to manage the family nursery business as his only brother was still at school and too young to take over the business.

In 1973 he decided to return to the Forest and Wildlife Service. However, this was an era before career breaks and Freddie had to re-apply for the post and sit an interview. He was successful in the interview and was appointed as assistant district inspector in Thurles. In 1981 he was transferred as assistant district inspector to Wicklow. In 1986 he was promoted as utilisation inspector in Mullingar. Following the setting up of Coillte in January 1989, Freddie was promoted as manager of new business and was based in Dublin. His final assignment in Coillte was as group health and safety manager. Freddie retired in June 2002 having availed of the early retirement package.

In retirement Freddie pursued a diverse range of educational disciplines from photography to learning Chinese, to woodwork and archaeology. In 2009 he received a Masters degree in maritime history from the University of Limerick. In 2011 he decided to continue his research in maritime history leading to a PhD degree at King's College, London but sadly his untimely passing did not allow the completion of his research. Freddie was a wonderful example of how to utilise one's retirement years to the full.

Freddie had varied sporting interests which ranged from supporting Wexford in hurling to Glasgow Rangers in soccer. He also had a keen interest in politics; he was an active member of Fianna Fáil and canvassed for that party in recent general election campaigns.

Coming from a nursery background Freddie understood better than most the science of plant breeding and production. He produced prize winning chrysanthemums for the Balmoral Show in Belfast a few years ago. He continued to enjoy experimenting in his greenhouse as recently as this spring.

He was a long-time member of the Society of Irish Foresters and attended many field-days and study-tours.

As a friend Freddie was sincere, loyal and generous. He was caring and charitable and always concerned for the less fortunate. He was particularly sympathetic to people affected by sickness or loss. Regardless of political persuasions or affiliation, he never allowed this to interfere with friendships. He had a strong religious tradition of which he was proud. He loved good company and was himself very entertaining when relating personal experiences.

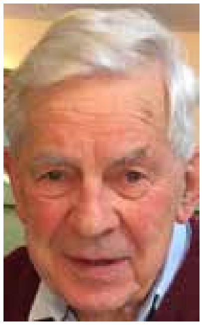
Above all, Freddie was a great family man, his beloved Elizabeth, his daughters Tanya and Sarah and adored grandchild, Olivia meant everything to him and to them we offer our sincere sympathy.

I know Freddie would share the sentiments of Michelangelo who wrote:

> *"If we have been pleased with life, we should not be displeased with death, since it comes from the hand of the same master."*

Michael O'Brien

Jim Neilan
1933-2016



On 8th July 2016 Jim Neilan, one of Ireland's best known nursery foresters, passed away peacefully at his home in Wicklow Town.

He was born, the second eldest of four children and the only boy, in Athleague, Co. Roscommon on 13th May 1933 to Michael Neilan and Brigid (née Garrick). After both his parents passed away at relatively young ages, Jim left Athleague in 1955 to pursue a career in forestry.

His group was the first to enter Kinnitty Castle Forestry College, Co. Offaly, he then moved to Avondale House because the extensive refurbishment works at Shelton Abbey were not complete. These works were necessary because the accommodation at Avondale House was unable to cater for the larger groups of foresters required to manage the increased afforestation programmes of the 1950s and 1960s. Jim completed his course at Shelton Abbey in 1958. Always keen on education, he completed a Masters degree in forestry 40 years later in 1998 and had plans to do a Ph.D. in his retirement.

His first assignment in 1958 was as an assistant forester in Kilworth Forest, Co. Cork. The following year he was appointed as house master at Shelton Abbey. In 1960 he was promoted to forester in charge, Grade 2, at Buncrana Forest, Co. Donegal. At that time foresters in charge were receiving cash for timber and lettings, and paying out cash as wages they had to sign a declaration as follows: "I am of sober habits, I am not addicted to betting and I am not financially embarrassed". In 1969 he transferred as a forester Grade 2 to Tinahely Forest and Nursery, Co. Wicklow. Since he had replaced a forester Grade 1, he requested that he be promoted to that same grade. Later that year, he was promoted to a forester Grade 1 - once again proving the point that if you don't ask you won't receive.

In 1983 he was promoted to the grade of senior forester with responsibility for Glenealy Forest and Nursery. On taking up this appointment he moved to live in Wicklow Town where he resided for the remainder of his life. It was inevitable that when Coillte was established in 1989, he would find a new niche and he was assigned the task of documenting and assessing Coillte's entire hardwood resource. He did an excellent job and was awarded a M.Agr.Sc. *(For)* for his research. His thesis was titled "Review of the Silviculture and Management of the Principal Broadleaved Tree Species Growing in Ireland". In May 1998 he retired having reached the age of 65.

Jim possessed a very innovative and enquiring mind and was motivated by the pursuit and understanding of concepts as much as in their implementation. He had an in-depth knowledge of the nursery business having worked in that field continuously for over twenty years.

During his years in Tinahely and Glenealy Jim trained a large number of students and young foresters. He was a strong believer in the benefits of life long education and always encouraged and facilitated those who were keen on further education. Always of a positive disposition, he encouraged young people by continually emphasising that forestry was a wonderful and rewarding career. He did his utmost to ensure that young students and foresters assigned to him had good accommodation and transport to work while they were with him - an attribute that was not as widespread as one might expect. In this regard he encouraged Richard Jack, while a young forester in the early 1980s, to undertake a history of the impact of forestry on Glenealy, an area steeped in the forestry tradition. Richard's project demonstrated how forestry was so hugely inter-connected with life in the community. It highlighted how much history and culture was incorporated in the forest estate. Consideration and preservation of local heritage during forest operations is essential in generating goodwill and healthy neighbourly relationships. This outlook was rare at that time but is now accepted as a vital component of forest planning.

Jim took a keen interest in the Society of Irish Foresters and facilitated many field days. He regularly attended field days himself and was a frequent participant on the Society's annual study tours. These he greatly enjoyed, always questioning and rationalising the reasons for carrying out a particular forestry operation. His most recent study tour was to Croatia in 2009.

In his youth Jim was a keen sportsman and he played inter-county hurling for his native Roscommon. He enjoyed retirement and was deeply involved with Wicklow Lions Club, the Toastmasters and Blainroe Golf Club.

Jim was predeceased by his wife Pauline at a very early age and deserves great credit for rearing three young children on his own. Their success in life is a testament to his dedication to them over the years.

To his son Paul, daughters Maria and Ciara, we offer our sincere sympathy.

Suaimhneas síoraí dá anam.

John Mc Loughlin

Letters to the Editor

www.rohanlon.org

The Editor, *Irish Forestry*

Re. Options to protect forest and plant health in Ireland

Dear Sir,

Some of the readers of *Irish Forestry* may have noticed Ben Haugh's piece on "The scourge of conker canker" in the *Irish Mail* on Sunday, 20th September 2015. In short, the article dealt with the increasing threat to Irish trees from non-native pest and pathogens, and featured an interview with the author Thomas Packenham. While I was very glad to see plant health issues getting such popular coverage, I do have some reservations over the tone and one of the conclusions of the piece. The aim of this letter is not to critique the newspaper article; rather I feel it offers a good opportunity to provide an alternative opinion to that of the article. In my opinion the conclusion of the article was rather defeatist in tone, conceding that the place of native Irish trees in Irish forestry may be finished. The article encouraged importing and planting non-native tree species to counteract the effects of the non-native pests and pathogens. This conclusion is based on the premise that these non-native trees have co-evolved with the non-native pest or pathogen in the region of origin, and so have a higher degree of resistance to the pest or pathogen than our native tree species. This is certainly true in some cases, as experiments and field observations have shown that ash species (e.g. *Fraxinus manshurica*) from the region of origin of the ash dieback pathogen (*Hymenoscyphus fraxineus*) show little or no disease symptoms when "infected" with the fungus[1]. Using a co-evolved ash species (e.g. *F. manshurica*) instead of our native European ash (*Fraxinus excelsior*) in future plantings may ensure most of the trees will not succumb to ash dieback, however there is also the possibility that resistance to the pathogen already exists in our native ash population, as has been shown in Denmark[2]. Indeed, preliminary results of the multi-institute UK funded research project NORNEX have shown high frequency of resistance genes in the UK *F. excelsior* population[3].

[1] McKinney, L.V., Nielsen, L.R., Collinge, D.B., Thomsen, I.M., Hansen, J.K. and Kjær, E.D. 2014. The ash dieback crisis: genetic variation in resistance can prove a long-term solution. *Plant Pathology* 63:485-499.

[2] Lobo, A., Hansen, J.K., McKinney, L.V., Nielsen, L.R. and Kjaer, E.D. 2014. Genetic variation in dieback resistance: growth and survival of Fraxinus excelsior under the influence of *Hymenoscyphus pseudoalbidus*. *Scandinavian Journal of Forest Research* 29: 519-526.

[3] Anon. 2016. An open consortium (NORNEX) for molecular understanding of ash dieback disease. Online: http://oadb.tsl.ac.uk/wp-content/uploads/2016/04/Nornex_Final_Report_April_2016.pdf

While I do not disagree in principal with the planting of non-native trees as a response to increasing pest and disease damage in Irish forests; I suggest that great caution be exercised in the implementation of such a step. Firstly, there are regulations in place to control the importation of plants and seeds into Ireland (see the Horticulture and Plant Health Division section on the Department of Agriculture, Food and the Marine website), or Northern Ireland (see the Plant and tree health section on the Department of Agriculture, Environment and Rural Affairs website), and these are designed to prevent the spread of non-native pests and pathogens. Despite these rules, it is known that some pests and pathogens do slip through the inspection net, and could go on to cause significant plant health problems. Importing any plant or plant reproductive material from another region brings with it the inherent risk that new pests and pathogens are present with the plant. A further problem with replacing native with non-native tree species is that we do not know the effect that our native flora and fauna (e.g. insects, fungi) will have on these non-native tree species once they are planted. Again using the ash dieback pathogen as an example, the pathogen was known as a benign fungus in Japanese forests, only exhibiting pathogenic behaviour when it encountered European *Fraxinus* species in the European environment. Who knows what effect any one of the 1,000's of seemingly harmless native Irish fungal, bacterial or insect species could have on these imported non-native tree species?

A better solution to the threat from current and future pests and pathogens on our forests is to increase the resilience of our forest estate by increasing forest tree diversity. This diversity includes several levels of diversity, such as species diversity (i.e. mixed species), genetic diversity (i.e. multiple provenances), and structural diversity (e.g. multiple age). This could provide a built-in buffering capacity within the forest, helping prevent major pest or disease epidemics[4]. Increasing the diversity would also provide increased resilience to climate change in the forest stand; and is also generally accepted to benefit native biodiversity. However, as always with forest planning, other factors need also be considered (e.g. soils, geography) in the choice of species, provenances and forest management strategies.

With a view to proactively preventing and mitigating against future pest and pathogen outbreaks in forestry, Ireland also needs to develop an indigenous capacity in the scientific disciplines of forest pathology and entomology. According to Dr Leslie Dowley (ex-Teagasc) there were 32 practicing plant pathologists in the research performing institutions on the island of Ireland in 1970, today there are only around 5. At present, I am the only full time specialist hired as a Forest pathologist on the island of Ireland. This decrease in expertise is happening at the same time as increases in the numbers of new pests and pathogens entering Ireland. Globally much of the work

[4] Ennos, R.A. 2015. Resilience of forests to pathogens: an evolutionary ecology perspective. *Forestry* 88:41–52.

previously carried out by plant pathologists is being transferred to molecular biologists; however, many of the skills involved in traditional plant pathology are still vital to our understanding of pathogen biology and epidemiology. Plant pathologists also have key responsibilities in public education and in contribution to national phytosanitary and biosecurity policy. The research performing institutes need to broaden their searches for future staff hires - if not hiring a dedicated plant pathologist then perhaps a microbiologist, environmental scientist or plant biologist with experience in plant/forest pathology. With many national and international funding bodies signalling an increase in the importance of plant pathology topics in their research policies (e.g. Department of Agriculture, Food and the Marine Ireland; Department of Agriculture, Environment, and Rural Affairs Northern Ireland; Biotechnology and Biological Sciences Research Council UK), the institutes need to respond to these policy drivers by hiring suitable staff to lead the work.

As an island off the west coast of Europe, Ireland has a significant natural defence against pest and pathogen invasions. However, we need to build upon this natural defence by investing in our scientific capacity in the fields of plant pathology and entomology. Institutes should be proactive and invest in this capacity now, rather than acting in response to future outbreaks. Plant pathogens are almost impossible to eradicate once introduced into a new region, therefore the national focus should be on proactive scientifically informed activities such as horizon scanning, pest risk analysis and contingency planning in an effort to safeguard Ireland's plant health for future generations.

Yours sincerely,

Richard O'Hanlon
Plant health and crop protection,
Sustainable Agri-food Sciences Division,
AgriFood and Biosciences Institute,
Belfast, Northern Ireland.

Association of Irish Forestry Consultants
May 2016

The Editor, *Irish Forestry*

Re. The acid sensitive designation

Dear Sir,

Forests provide a range of raw materials for industry as well as services to society. One particular service provided by forests, climate change mitigation, works by removing and locking up carbon dioxide from the atmosphere. In the Irish context this entails the need to continue afforestation at a level in the region of 15,000 to 20,000 ha per annum for the next two decades. Achievement of this goal will not only sustain the ability of the national forest estate to remove carbon dioxide from the atmosphere and store it in the vegetation and soil, it will also provide a renewable energy resource and a sustainable raw material for construction, a range of other timber uses as well as other environmental and social benefits.

Expansion of the national forest estate is a key component of national climate change and land use policy. The average afforestation levels over the last five years has been 6,000 to 7,000 ha per annum. There are a number of issues affecting land availability for afforestation, one particular difficulty is that the planting programme is being restrained by a lack of current scientific research which can defend against spurious assertions and promote our forest industry.

Acid Sensitive Designation

The "acid sensitive" designation has had a significant adverse impact on afforestation levels in a number of counties over the last ten years. Many professional foresters and agriculturalists have questioned the science being applied, particularly in relation to enclosed agricultural land (typically rushy fields) that in most cases is ideal for afforestation. Much of the research studies in relation to acidification have focused on the potential negative impact of afforesting open moorland underlain by acid rock, while foresters and land owners are being refused permission to plant trees on improved enclosed agricultural land with inherently better buffering capability.

The main farming enterprise on this land type is livestock production. The hypothesis of possible negative acidification impacts of forest canopies scrubbing aerosols (mainly nitrogen and sulphur compounds) from the atmosphere does not take into account the other positive benefits associated with forestry versus continuing with current agricultural practices, in particular the significant methane emissions from livestock. We have yet to see a report that looks at the positive and negative impacts on the environment of continued cattle production versus the positive and negative environmental impacts of forestry on the same acid sensitive enclosed farmland.

The acid sensitive designation is now 25 years-old, it was coined at a time when the threat of acid rain was one of the main environmental concerns across Europe. The designation should now take into account the industrial and technological changes in the last quarter century. It would be useful for our industry to see an investigation into what was predicted against what has actually occurred in terms of acidification outcomes. National and international legislation have successfully resulted in reduced and cleaner emissions from heavy industry, especially with regard to sulphurous compounds. The threat posed by airborne pollutants in the atmosphere being scrubbed by coniferous forest canopies on the western half of Ireland, given that the prevailing wind is predominantly from the southwest, has to be minimal and the present designation represents a dramatic overkill.

Is this Acid Sensitive designation a genuine effort to protect and improve water quality or a crude instrument to stop conifer afforestation, particularly when the anti-coniferous and anti-forestry lobbying context of the time is considered? Replacing uneconomic livestock production which is the main farming activity in these areas with forestry would have many measurable environmental and financial benefits. As John Shirley pointed out in the *Farming Independent*, it makes eminently more environmental and financial sense to control rushes with trees than with MCPA herbicide (Table 1).

Doubling our current afforestation rate has been highlighted by government as being central to Irelands Climate Mitigation Strategy. It is essential that the current measures which exclude over 150,000 ha of productive land, solely on the basis of an outdated acid sensitive designation, be revised to allow all enclosed farmland to be considered potentially suitable for the GPC3 (10% Diverse Conifers[1]) category for afforestation. The threat posed to our climate is from excess carbon and no longer from acid rain.

Yours sincerely,

Dermot Houlihan, Chairman of AIFC.

[1] GPC 3 is 90% Sitka spruce and 10% other coniferous species.

Table 1: *A comparison between agricultural and forestry enterprises in a typical gley soil area.*

Cattle farming	Forestry
Net greenhouse gas source (carbon emissions).	Carbon sink.
Annual broadcast application of NPK (compound fertiliser) and in many cases 2 applications per annum. This equates to 25-50 kgs N ha^{-1} yr^{-1}. N decreases soil pH.	One application of P as ground rock phosphate (GRP) @ 250 kgs ha^{-1}) in 30 years. GRP has pH of 8+ and increases soil pH.
Land can be ploughed or tilled as frequently as farmers wish and will have 90% topsoil disturbed leading to significant carbon release.	Land mounded in year 1 of a 30-year cycle with approximately 6% of topsoil disturbed.
Annual control of soft rush by topping with machinery and broadcast spraying with MCPA (herbicide) to achieve GAEC (Good Agricultural and Environmental Condition) and minimal setback from watercourses.	Manual control of vegetation for 4 years with perhaps one to two spot sprayings with herbicide (Roundup) over 30 years (i.e. 25% of area). No spraying within 10 m of watercourses.
Slurry from animal production is applied to full area -equivalent of 15 kgs N ha^{-1} yr^{-1} generating further GHG emissions to the atmosphere.	No animal waste applied.
Heavy machinery used on farmland several times per annum.	Machinery only used for thinning and felling (maximum of 5 times in 30-year rotation).
Rainwater runoff enters drains with minimal vegetation to slow it down.	Forests intercept and slow water cycling. Silt traps are mandatory in all forestry drainage.
Farming extends right up to watercourses	Forests are setback 10 m from watercourses for all operations.
Animal drinking areas in commonly located within watercourses allowing animals to defecate into watercourses.	N/A
Minimal wildlife areas, mainly confined to hedgerows.	Entire plantation area has wildlife habitat potential.
Agricultural enterprises on surface water gley soils regarded as marginal.	Surface water gley soils are highly productive forest areas.
Poor farming outcomes and marginalisation.	Better livelihoods.

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