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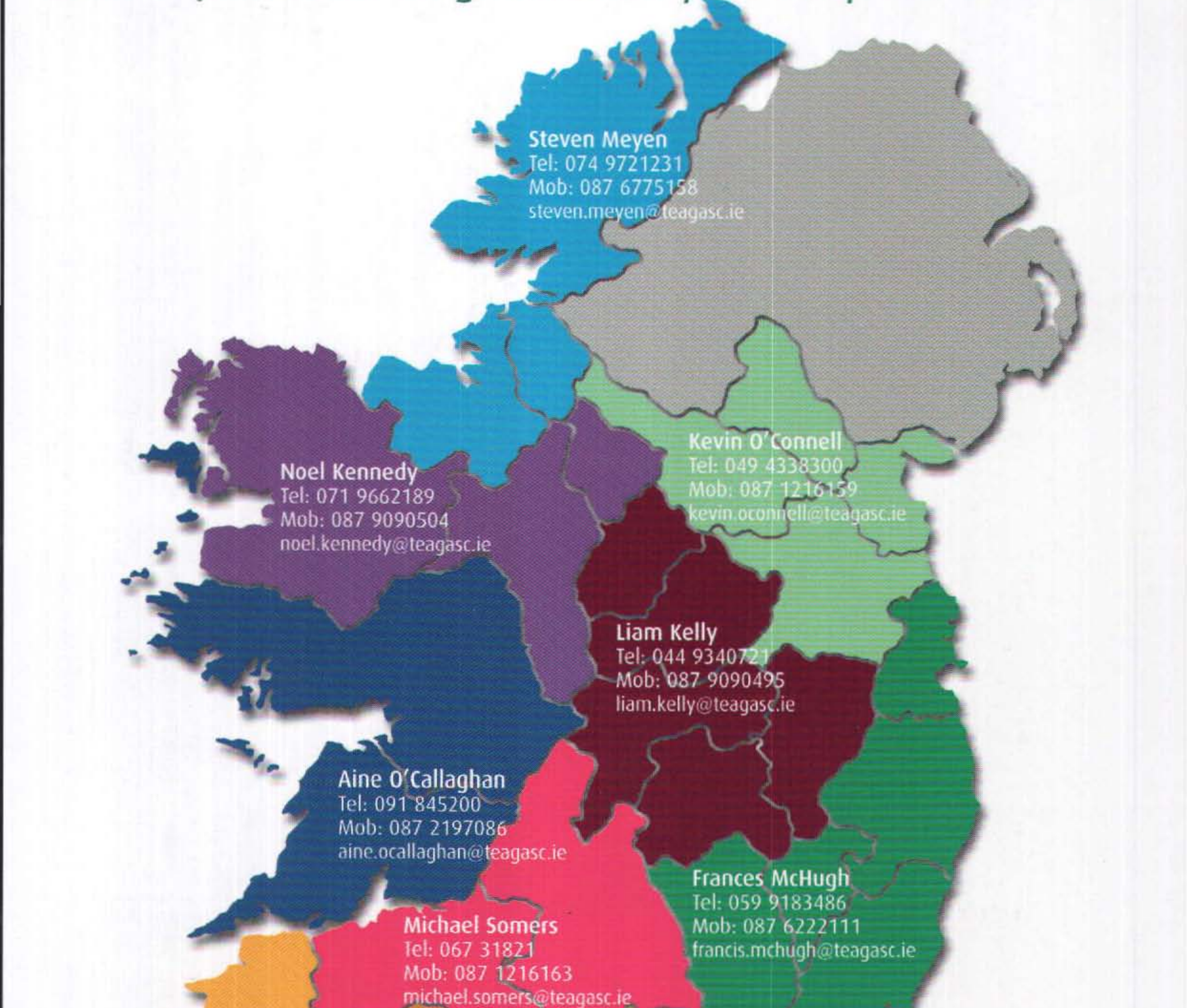

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Society of Irish Foresters
Enterprise Centre
Ballintogher
Co Sligo
Ireland
Tel: 071 9164434
Fax: 071 9134904
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EDITORIAL

Afforestation - never more relevant to national policy

Expanding the forest cover of the country has been a cornerstone of forest policy since the establishment of the state. The rapid pace of expansion over the past two decades has led to a forest estate that now covers well over 10% of the area of the Republic. Moving to the 17% forest cover target may be difficult to achieve in the timeframe envisaged, but it is nonetheless critical that afforestation continues at a level of at least 10,000 ha per annum. Current indications are however that afforestation is running at well below that level, and heading downwards. Already there have been knock-on effects for nurseries and contractors. In the longer term, reduced afforestation will seriously impact on competitiveness and sustained wood supply, and the provision of environmental services.

One of the main environmental services that Irish forests provide is mitigating climate change through uptake of carbon dioxide. Their ability to fulfil this role into the future, while at the same time providing raw material for sawnwood, panel production and energy, depends on sustained afforestation to compensate for harvest. Here is a classic application of the sustained yield principle, allied to the concept of the normal forest – the production of goods and services in perpetuity. Analysis of the afforestation programme since 1985 in terms of future wood harvest and carbon sequestration shows that a further 20 years of afforestation, at a minimum of 10,000 ha per annum, is needed for forests to fulfil the multifunctional role that national policies now demand. Otherwise it will not be possible to satisfy both climate change and raw material demands.

Energy wood will be the first assortment that will suffer from reduced afforestation, given that it is sourced mainly from first thinnings. Ambitious targets for the use of wood derived energy have been set in the recent government Energy White Paper and in the Bioenergy Action Plan. These policies foresee wood fuel making a signifcant contribution to renewable energy generation, leading to reduced fossil fuel use. While these developments offer exciting prospects for the next decade, projections indicate that the supply of energy wood will gradually tail off as the current reduced afforestation levels begin to impact. How will the gap be made up? Already there is a growing import of wood pellets for domestic heating. Will this extend to wood chip for commercial applications, or even for power generation? The answer to these questions will depend on price and availability, and on government policy.

One of the main reasons for the reduction in afforestation has been the impact of the REPS scheme. While REPS may be contributing to biodiversity conservation and water quality, there has been little appraisal of its effectiveness. Given this fact and the need to prevent the collapse of the afforestation programme, the time has come for a fundamental reappraisal of agricultural grant aid policy to bring it more into line with future energy and climate change needs. Will it make economic sense to have boatloads of woodchip and pellets coming into the country, while at same time having a signifcant part of the country being farmed at well below its productive and bio-economic potential, as a direct consequence of national policies? Biodiversity conservation and enhancement are laudable policy objectives but need to be balanced by catering to future energy needs, securing reliable energy on the island, and by the need to address the greatest environmental threat facing mankind - climate change.

Afforestation can provide a significant part of the answer to these challenges, and has never been more relevant to national policy.

An early assessment of Irish oak provenance trials and their implications for improved seed production

Derek Felton[a], David Thompson[b] and Maarten Nieuwenhuis[c]

Abstract
In order to evaluate the qualitative and quantitative performance of a range of Irish oak provenances a series of provenance trials was established at four sites (Camolin, Durrow, Belturbet and Donadea) in 1988. An assessment was made of all four trials during the dormant seasons of 2001/02 and 2003/04. Variables assessed were species, flushing characteristics, survival, height, girth, straightness, apical dominance and forking height. Results showed consistent variation in performance between provenances across the four trials. The geographic distribution of good and poor provenances was discontinuous across the country, and in spite of their poor phenotypic appearance, some stands that had the best trees removed still contained genes for good growth and stem form. Recommendations are made regarding the status of the various oak provenances in relation to the continued development of a seed resource for Irish forestry.

Keywords: Oak, native species, provenance trial, improvement seed harvesting

Introduction
Renewed interest in broadleaf afforestation, together with the introduction of the Native Woodland Scheme in 2002, have significantly increased demand for native broadleaf planting stock. While seed of many native tree species, including ash (*Fraxinus excelsior*), birch (*Betula* spp.), alder (*Alnus glutinosa*), and yew (*Taxus baccata*) is readily and consistently locally sourced, seed of other species, particularly oak (*Quercus* spp.) and hazel (*Corylus avellana*), is less plentiful. Under Irish climatic conditions, oak does not produce seed consistently every year. Mast years occur infrequently and irregularly, often at intervals of five years or more. The European Union Directive on the marketing of forest reproductive material (1999) stipulates that oak seed be sourced from Registered Seed Stands; while seed used in the Native Woodland Scheme may be collected from source identified stands. There are at present (2006) 21 sessile oak (*Q. petraea*) and 25 pedunculate oak (*Q. robur*) registered seed stands in the Irish Republic, comprising a total area of 864 ha. In addition, there are 25 source-identified oak seed stands, covering over 1,000 ha. Many of these stands are isolated semi-natural remnants, and none are at present managed for seed production.

Seed production in oak in Britain starts at 35 to 40 years for open grown trees and 40 to 50 years in closed stands (Evans 1984). Trees grown for seed production should

[a] Forestry consultant and contractor, Shankill, Co Dublin, Ireland (corresponding author, derekfelton@ireland.com).

[b] Coillte Teoranta, Kilmacurra Park, Kilbride, Co Wicklow, Ireland.

[c] UCD School of Biology and Environmental Science, University College Dublin, Belfield, Dublin 4, Ireland.

be widely spaced to encourage maximum production at younger ages. All phases of reproductive development, from flower initiation to ripening, are determined by climate (Gordon and Rowe 1982).

It has been commonplace in oakwoods in both Britain and Ireland for better quality, higher value stems to be removed, resulting in genetic impoverishment. An individual is a product of genotype and environment, and the latter has enormous influence on volume production, stem form and branching characteristics (Crowther 1982). Nevertheless, the phenotype provides little reliable information about the genetic qualities of the individual. This can only be determined by growing offspring of the parent in comparative provenance trials[1]. Fully reliable conclusions regarding growth and stem form in oak should be available after 25 to 40 years.

Objectives

The original objectives of the provenance trials were:

1. to identify the best seed source of native oak for commercial forestry purposes,
2. to examine genetic variation within and between native oak provenances,
3. to provide a base for further ecological studies, and
4. to create a gene pool to safeguard a threatened genetic resource.

The aim of the work reported here was primarily to determine whether there were significant differences in productivity, quality and stem-form between the provenances, across the four locations, and thereby to identify the potentially best genetic seed resources.

Materials and methods

In the autumn of 1984, a prolific mast year, acorns were collected from 29 oak stands (believed to be native or semi-natural) throughout the country (Appendix 1). After three years in the nursery, the provenances were established in replicated field trials at four locations. Provenance details are provided in Appendix 1. Assessments reported here were carried out during the winters of 2001/2 at age 13 (Camolin, Belturbet and Donadea) and 2003/04 at age 15 (Durrow).

Trials

The location, site description and establishment methods used in the establishment of the oak provenance trials are presented in Appendix 1. The same plant spacing - 1.2 m in and between lines - was used at all the trials.

<u>Belturbet</u>

Fifteen provenances are represented, 13 in three replications, with the remainder in two replications only. There are 43 plots of 225 trees (15 x 15). The site is moderately sheltered, slopes to the SE and has had non-oak competing trees removed.

[1] Comparative provenance testing is undertaken by the selection of seed within the natural range, raising the seedlings and deploying them in replicated field trials at different locations, on a variety of soil types (Wright 1976).

Camolin

The Camolin trial is the largest; twenty-seven provenances are present in a randomised block design with three replications (three provenances are present in two replications only). In addition, one plot comprises seedlings from the Royal Oak in Tomies Wood in Killarney National Park. In all, there are 79 plots of 225 trees (15 x 15). The site is sheltered from the southwest by a boundary ditch with mature beech, which influenced the growth in the adjacent oak plots. Initially, the shelter provided by the beech encouraged early growth, but now the effect of shading is notable in lines immediately adjacent to the beech through reduction in vigour and crown size. A further factor influencing the growth of the oak has been the presence of naturally seeded birch, since removed. Growing more rapidly than the oak, the birch, restricted its growth. Birch competition was present in 23 of the 79 sample plots.

Donadea

Located on cutaway peat, this trial comprises eleven provenances (ten in four replications and one in three replications only) in 43 plots of 144 trees (12 x 12). The site is level and moderately sheltered. Although this trial received fertilizer at establishment (350 kg P ha^{-1} and 250 kg K ha^{-1}), growth was poor. However, weed competition was minimal.

Durrow

Nineteen provenances are represented in three replications comprising 57 plots of 221 trees (17 x 13). The site is level with a sheltered northwest aspect. As in Camolin, competition from tree species - ash, birch and willow - has suppressed the growth of the oak throughout the trial.

Species identification

In order to identify the species present in each provenance, 20 litter leaves were collected from the centre of each plot in the first replicate at the Camolin trial. These were then analysed for diagnostic characteristics using the method described by Potter (1996). Petiole percent (P) was calculated from the total petiole length (p) and leaf length (l), the ratio (p/l) being expressed as a percentage of total leaf length ($P = 100*p/l$). Lobe pairs were also counted. Morphology was qualitatively assessed for sessile or pedunculate characteristics. Sessile features were scored +1, pedunculate -1, with intermediate features scoring 0. Distinguishing characteristics are summarised in Table 1.

Flushing

Seven flushing assessment was carried out at Camolin between 10 April and 15 May 2002, on the leading shoots of nine trees from the edge to the centre of each plot. Degree of flushing was scored as: 0 bud dormant, 1 bud swollen, 2 first green leaves, 3 fully flushed, 4 shoot elongation. Means were calculated for plots and provenances.

Table 1: Leaf characteristics of pedunculate and sessile oak (Potter 1996).

	Species			
Characteristic	*Pedunculate*		*Sessile*	
Petiole ratio	*Low (1-10)*		*High (5-18+)*	
Number of lobe pairs	*Few (2-6.5)*		*Many (4.5-8+)*	
Leaf index		*Score*		*Score*
Lobe morphology	*Deep irregular*	*-1*	*Shallow regular*	*+1*
Auricles	*Strong*	*-1*	*Weak or absent*	*+1*
Abaxial hairs	*Absent*	*-1*	*Present*	*+1*

Survival

Numbers of dead or missing trees were recorded in each trial plot, without differentiation, and mean survival percentages calculated for each provenance in each trial.

Tree growth and form

The central nine trees were measured in each plot in 2001 at the Belturbet, Camolin and Donadea trials. At Durrow (2003) the central line of 13 trees were sampled. Height was measured in decimetres and diameter (dbh) in centimetres. Form was visually assessed for straightness, apical dominance and forking height, on a scale of 1 (poor), to 4 (good) (Table 2).

Statistical analysis

To reduce the influence of competing vegetation and to better assess performance under managed conditions, a parallel analysis was carried out using data from the best/tallest three trees (B3) in each sample plot. Plot and B3 means, standard

Table 2: Oak stem form rating system.

Stem form variable			
Straightness	***Apical dominance***	***Height to first fork***	***Score***
Very crooked	*Bushy top, >5 leaders*	*<2 m*	*1*
Bent	*Multi-leadered, >3-5 main shoots*	*2-3 m*	*2*
Straight	*Two main shoots*	*3-4 m*	*3*
Plus stem	*One main shoot*	*>4 m*	*4*

deviations and Z-scores were calculated for each variable, for each provenance. Unless otherwise indicated, mean provenance B3 results are presented throughout.

In order to compare the performance of the provenance variables between different trial locations, and across time, mean plot Z-scores were used as the dependent variable. The Z-score is the number of standard deviations that the sample is removed from the sample mean. In normally distributed populations, 68% of values are found between +1 and -1 standard deviation (equivalent to a Z-score of +/- 1). All B3 data were tested for normality using the Kolmogorov-Smirnov criterion. Excluding the cases wehre no test statistic could be calculated (because the three observations were identical), the data were normally distributed in almost all cases, justifying the use of Z-scores.

Taking the survival rates of the Abbeyleix (ABX) provenance (Appendix 2) as an example: a Z-score of -0.4 at the Camolin trial indicates that the survival rate for ABX in the Camolin trial, being within one standard deviation of the trial mean, is close to the average for the trial as a whole, whereas at the Durrow trial the corresponding survival Z-score of -2.0 indicates that the ABX survival rate is significantly lower than the Durrow trial mean.

Results

Species identification

Twenty of the 27 provenances present in the Camolin trial were identified by leaf analysis as sessile oak (*Quercus petraea*), and seven as pedunculate (*Q. robur*). The two additional provenances absent from the Camolin trial were identified as sessile from material collected at the Donadea trial. The provenances were grouped into four geographic regions after species identification: southwest sessile, northwest sessile, southeast sessile and central pedunculate (Figure 1). *Q. robur* is typically found on deep calcareous clays in the midlands, while *Q. petraea* occurs predominantly on poorer more acidic soils in the wetter Atlantic regions and at higher elevations (Cross 1987).

Leaf Index (LI), ranging from +3 (sessile) to -3 (pedunculate), was plotted against number of lobe pairs and petiole ratio, in a pair of scatter diagrams to assign species (Figures 2 and 3).

Leaf analysis indicated that the progeny of the sessile oak provenances were largely pure, exhibiting little introgression; the one exception to this norm being the Enniskerry (ESK) source which showed some pedunculate and intermediate characteristics. This contrasts with the findings of Rushton (1979) in Northern Ireland where all of the sampled sessile oak stands showed some degree of hybridization. On the other hand the pedunculate oak progeny, with the exception of the Charleville Island (CHI) provenance, all showed intermediate characteristics. Both the Cahir (CHR) and Cootehill (COO) provenances were best described as hybrids.

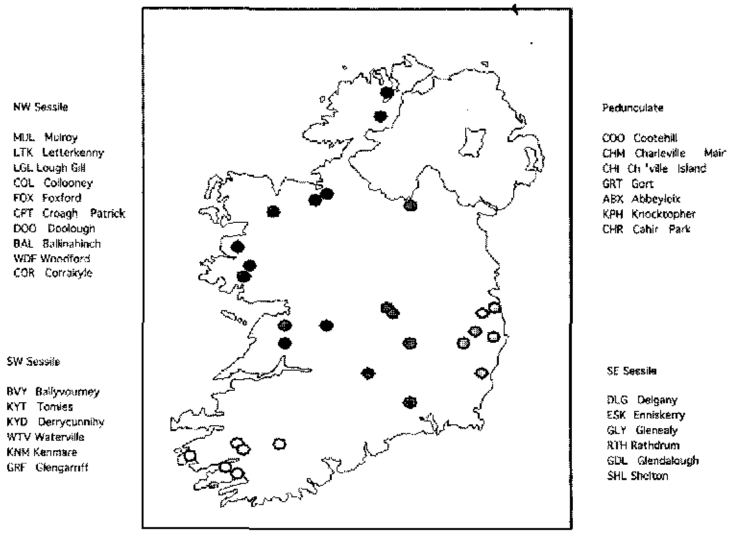

Figure 1: Geographic and species groupings attributed to oak provenances, together with codes.

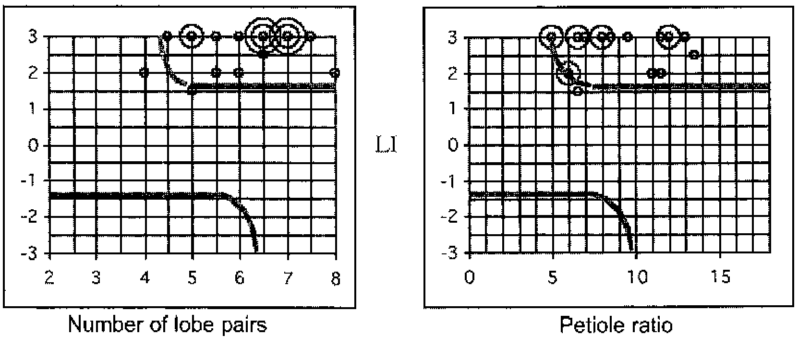

Figure 2: Typical sessile oak scatter diagram Killarney Derrycunnihy (KYD).

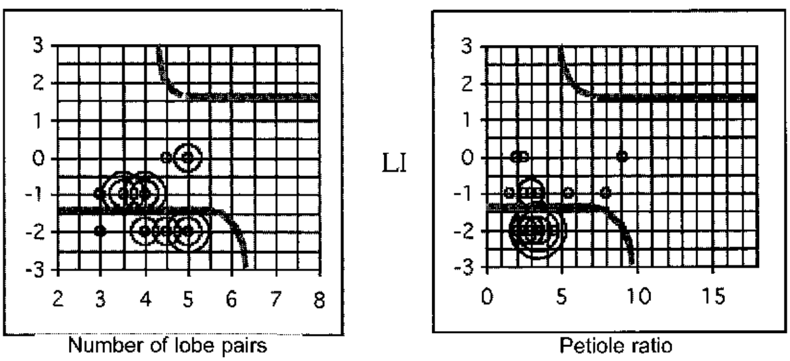

Figure 3: Typical pedunculate oak scatter diagram Abbeyleix (ABX).

Flushing
There was little difference between provenances in flushing date, all flushed within a period of seven days, well within the expected range in a natural tree population. An analysis of the mean flushing rates of the four provenance groups indicated that the NW and SE sessile groups were fully flushed four days before the SW sessile and pedunculate groups.

Survival
Survival rates varied little within the three main trials (Table 3 and Appendix 2), the highest rate being recorded at Camolin where two provenances (Glengarriff (GRF) and Charleville Island (CHI)) were fully stocked in all sample plots. Low survival rates were recorded at the Donadea trial, particularly within the SW and SE sessile groups; this may have been due to frost damage. However, both pedunculate provenances present Charleville Island (CHI) and Gort (GRT)) showed good survival rates in this trial.

Above average survival rates were recorded across the trials for Charleville Island (CHI), Ballinahinch (BAL) and Rathdrum (RTH), while consistently below average scoring provenances included Abbeyleix (ABX), Foxford (FOX), Collooney (COL) and Waterville (WTV).

Table 3: Mean survival rate and range of oak at each of the trial locations.

Location	***Mean***	***Range***
	%	
Belturbet	*80.0*	*54.4 to 88.8*
Camolin	*87.7*	*74.4 to 100.0*
Donadea	*75.5*	*44.4 to 94.4*
Durrow	*82.1*	*66.7 to 94.9*

Tree height
Mean tree heights ranged from 3.5 m at Donadea to 5.6 m at Camolin (Table 4). The B3 heights for Lough Gill (LGL), Enniskerry (ESK), Gort (GRT) and Corrakyle (COR) provenances were consistently well above average, across all locations (Appendix 3). The Foxford (FOX) provenance scored similarly well in all trials excluding Donadea. Consistently poor performers across the trials include Cahir (CHR), Killarney Tomies (KYT), Kenmare (KNM) and Collooney (COL). A summary of height and dbh Z-scores results is shown in Figure 4.

Diameter
Higher mean plot and B3 dbh values were recorded at Belturbet and Camolin, while the values at Durrow (measured three years later) were comparatively lower (Table 5). Breast height diameters at Donadea were significantly lower. Good results across

Table 4: Mean height and height range, for sample plots and B3, at each of the trial locations.

Location	Assessment year	Plot (9 trees) Mean	Plot (9 trees) Range	B3 Mean	B3 Range
		m			
Belturbet	2001	4.9	3.7 to 5.9	5.5	3.7 to 6.5
Camolin	2001	4.7	3.1 to 6.7	5.5	3.8 to 7.6
Donadea	2001	2.5	1.0 to 4.0	3.3	2.3 to 5.0
Durrow	2004	4.6	3.8 to 5.5	6.8	6.0 to 7.6

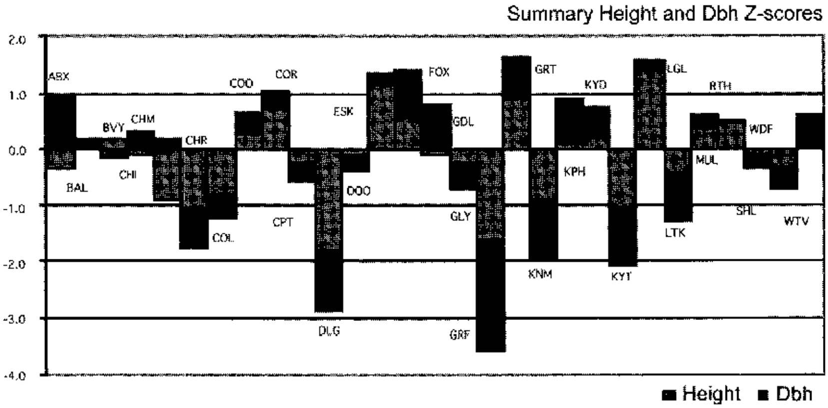

Figure 4: Summary of height and dbh Z-scores for Best 3 data.

Table 5: Mean diameter breast height and diameter range, for sample plots and B3, at each of the trial locations.

Location	Assessment year	Plot (9 trees) Mean	Plot (9 trees) Range	B3 Mean	B3 Range
		cm			
Belturbet	2001	5.3	1.7 to 6.7	6.5	4.8 to 8.7
Camolin	2001	4.9	3.1 to 7.1	6.3	2.7 to 9.0
Donadea	2001	2.9	1.0 to 4.8	4.2	1.0 to 7.3
Durrow	2004	3.8	2.9 to 4.5	6.1	4.7 to 7.6

locations were recorded for Knocktopher (KPH) and Foxford (FOX) provenances, although Foxford performed poorly at Donadea (Appendix 4). The dbh values for Abbeyleix (ABX) were exceptionally high at Camolin, and just below average at Durrow. Of the remaining provenances, only Corrakyle (COR) scored consistently above average.

The Letterkenny (LTK) and Killarney Tomies (KYT) provenances had lower dbh than the other provenances at all four sites. Although Kenmare (KMN) had better than average values at Camolin, this provenance scored well below average in the other three trials. The B3 mean provenance diameters and Z-scores are shown in Appendix 4.

Volume production (as a function of height and diameter) was highest for the Lough Gill (LGL), Gort (GRT), Foxford (FOX), Enniskerry (ESK) and Corrakyle (COR) provenances (see Figure 4). The poorest volume producing provenances were Glengarriff (GRF) and Delgany (DLG), although both were represented at the Camolin location only. The Collooney (COL), Kenmare (KNM), Killarney Tomies (KYT) and Letterkenny (LTK) provenances had low values at all locations.

Form

The three stem form characteristics visually assessed and rated were straightness, apical dominance and forking height. All the stem form data by provenance are presented in Appendix 5. Taller trees tended to be straighter, had a single leader and a greater forking height (>4.0 m). Competing woody vegetation, particularly birch, reduced the overall form scores at the Camolin and Durrow trials.

A summary of the B3 Z-scores for the three form characteristics is shown in Figure 5. Those provenances with better overall form included Charleville Main (CHM), Delgany (DGL) and Glendalough (GDL), all of which are present at the Camolin trial only. Across the trials the Gort (GRT), Killarney Derrycunnihy (KYD)

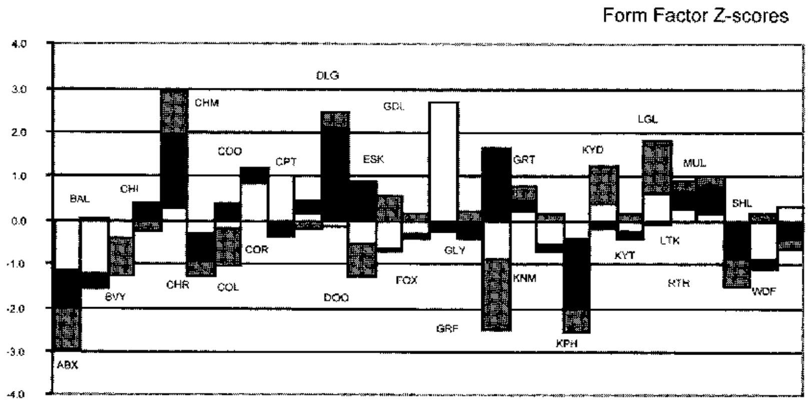

Figure 5: Summary of form (straightness, apical dominance and forking height) Z-scores for Best 3 data.

and Lough Gill (LGL) provenances had above average stem form. Particularly poor provenances included Abbeyleix (ABX), Glengarriff (GRF) and Knocktopher (KPH).

Straightness

While the Glendalough (GDL) provenance scored exceptionally well for straightness at Camolin, of the provenances represented at more than one trial, Cootehill (COO), Corrakyle (COR), Lough Gill (LGL), Killarney Derrycunnihy (KYD) and Waterville (WTV) had consistently higher straightness scores. Abbeyleix (ABX), Ballinahinch (BAL) and Woodford (WDF) all scored below average throughout (Table 6 and Appendix 5).

Apical dominance

The two Charleville provenances (CHM and CHI), together with Delgany (DGL) and Glengarriff (GRF) (Camolin trial only), and Letterkenny (LTK) and Mulroy (MUL) all had above average apical dominance. Abbeyleix (ABX), Knocktopher (KPH) and Woodford (WDF) had consistently below average scores (Table 7 and Appendix 5).

Table 6: Mean and range of straightness scores, for sample plots and B3, at each of the trial locations (1 -weak, 4 - strong).

	Plot (9 trees)		*B3*	
Location	*Mean*	*Range*	*Mean*	*Range*
Belturbet	2.0	1.8 to 2.4	2.3	1.9 to 2.9
Camolin	2.3	1.5 to 3.0	2.5	1.7 to 3.7
Donadea	2.0	1.8 to 2.2	2.2	1.8 to 2.5
Durrow	2.2	1.9 to 2.6	2.8	2.2 to 3.2

Table 7: Mean and range of apical dominance scores, for trial plots and B3, at each of the trial locations (1 - weak, 4 - strong).

	Plot (9 trees)		*Best 3*	
Location	*Mean*	*Range*	*Mean*	*Range*
Belturbet	2.0	2.1 to 2.7	2.3	2.3 to 3.1
Camolin	2.3	1.5 to 3.0	2.5	1.7 to 3.7
Donadea	1.9	1.6 to 2.3	2.3	1.8 to 2.7
Durrow	2.6	2.2 to 3.1	3.5	2.8 to 3.8

Forking height
The average forking height at Donadea was significantly lower than at the other locations. Durrow had the highest forking height, with B3 values averaging above 3.5 m, and many of the plots unforked to 4.0 m (Table 8). The better provenances included Enniskerry (ESK), Killarney Derrycunnihy (KYD) and Lough Gill (LGL). Those with a lower than average forking height included Abbeyleix (ABX), Ballyvourney (BVY), Collooney (COL), Knocktopher (KPH) and Woodford (WDF) (Appendix 5).

Discussion

The best performing provenances overall, with the exception of those included at only one location, were Cootehill (COO), Corrakyle (COR), Killarney Derrycunnihy (KYD), Gort (GRT), Lough Gill (LGL), Enniskerry (ESK), and Mulroy (MUL). The poorest were Cahir (CHR), Collooney (COL), Doolough (DOO), Kenmare (KNM) and Killarney Tomies (KYT).

The most striking feature of the overall results is the discontinuous geographic distribution of good and bad performers. In all three of the sessile groups, the best and worst performers are immediately adjacent: in the Sligo region (NW sessile group) the Lough Gill (LGL) provenance is the best overall performer, while Collooney (COL), the nearest provenance within the group (less than 10 km to the west), is one of the worst. There are, however, a number of other oak woodlands in the immediate vicinity, including those at Hazelwood and Slishwood, and some others, about which nothing is known of the progeny. Within the SW sessile group, Killarney Derrycunnihy (KYD) performed well, while Killarney Tomies (KYT) is one of the worst overall. These stands are less than 5 km apart, and there are numerous other oakwoods to be found within the Killarney National Park, which are not represented in the trial (see Kelly 1981). Within the SE sessile group, Enniskerry (ESK) performed well, while Delgany (DLG) was a poor performer. These stands are located less than 5 km apart, and, again, there are a number of oak woodlands within the adjacent Powerscourt demesne and along the Dargle River that were not included in the trial.

Table 8: Mean and range of forking height scores, for sample plots and B3, at each of the trial locations (1 - low, 4 - high).

	Plot (9 trees)		*Best 3*	
Location	*Mean*	*Range*	*Mean*	*Range*
Belturbet	*2.5*	*1.5 to 3.6*	*2.9*	*1.3 to 4.0*
Camolin	*2.3*	*1.0 to 3.8*	*2.7*	*1.0 to 4.0*
Donadea	*1.5*	*1.0 to 2.7*	*1.8*	*1.0 to3.7*
Durrow	*2.6*	*2.1 to 3.2*	*3.6*	*3.1 to 4.0*

Information on the 'localness' (semi-natural woodland or old plantation) as well as information on past management practices are often incomplete or simply not available for oakwoods in Ireland. Some of the phenotypically poorer stands produce good progeny, suggesting that, although best individuals may have been removed, the genes are still there. These trials open a small window on the Irish oak population throwing some light on the potential to improve seed quality, but leave us in the dark regarding all those oak stands not featured in the provenance trials.

Results from this study agree broadly with an earlier assessment of the trial undertaken in 1999 (Thompson and Lally). However, Thompson and Lally listed Killarney Derrycunnihy (KYD) and Killarney Tomies (KYT) as seed sources to avoid. Results presented here rate Killarney Derrycunnihy (KYD) among the best overall. In addition, a number of high scoring provenances in this study (Cootehill (COO), and Enniskerry (ESK)) were not included in the Thompson and Lally recommendations. This may be due in part to the fact that their recommendations were made from a very early assessment after only 8 growing seasons. Kleinschmidt (1999), working on a 40-year-old oak provenance trial in Germany, found a negative correlation between early and later height assessment measurements, (r -0.75) until year 17. The trials assessed here was 13 and 15 years old, and, as a result, the data should not be considered definitive. Kleinschmidt also found that the best performances came from provenances well known for their overall quality, the phenotypic properties of the parents being well represented at the trials.

This raises the question of sourcing acorns both for commercial broadleaf forestry and the Native Woodland Scheme. Present demand for planting stock far outstrips available harvestable supplies of acorns. Between private and state afforestation/reforestation there is an annual requirement of about 30 tonnes (P. Doody, Seed Manager, Coillte, personal communication). Present indications are that there will be a significant take-up of the Native Woodland Scheme, dramatically increasing the demand for native-sourced oak. The present home-collected acorn harvest has yet to exceed 7.5 tonnes in any one year, although there is the potential to increase this amount. There are five ways this could be done:

1. *silvicultural management*: while not specifically applicable to native stands, a number of phenotypically superior non-native registered oak stands (e.g. Donadea, Kilcooly and Rahin) are very closely spaced, giving rise to trees with proportionally small crowns. Appropriate thinning to favour seed-bearing trees with better form and deeper crowns would allow the development of larger crowns and thus more seed production.
2. *browsing protection*: browsing considerably reduces the potential for seed harvesting in many existing registered stands. Culprits include all deer species, all livestock (acorns are poisonous to cattle, particularly calves), rodents, and many bird species including crows, pheasants and pigeons. Deer have proven to be particularly voracious acorn feeders, as typified by the experience in Charleville during 2004 where acorns falling overnight onto nets were completely cleared by noon of the following day. Protection of stands, and in some cases individual trees, would greatly reduce this loss. Temporary stock exclusion using electric fencing has proved sufficient to date at some sites.

3. *ground vegetation control*: the most efficient way to harvest acorns is using nets. This method is particularly useful for open-grown trees with large crowns but can only be used if the ground vegetation does not prevent the laying of nets. Prior to harvesting, vegetation control, especially of bilberry (*Vaccinium myrtillus*), briar (*Rubus* spp), grass and woodrush (*Luzula* spp), greatly facilitates harvesting, even without nets. Invasive species, particularly rhododendron (*Rhododendron ponticum*), laurel (*Prunus lusitanica*), and native shrubs and trees make it impossible to lay nets and difficult to find acorns on the ground.
4. *more collectors:* acorn harvesting is non-specialised work, even with the use of nets, and can be a pleasant and worthwhile experience for all, from primary school children to retirees. It is vital that acorns are continually collected throughout the month of October, so potential collectors should be located close to harvestable stands. While sharp frosts and gales cause the acorns to fall, the drop is more a continuous 'rain' throughout the month as frosts are uncommon in October, although visiting a site after a strong wind is usually very rewarding.
5. *registered stands*: many native Irish sessile oakwoods are small isolated remnants, and, while the larger well known woods are registered, there are numerous additional stands and districts (with dispersed oak remnants) with registration potential. Much of the pedunculate oak, established during the 18-19th centuries, was estate planted; much of which has been felled. However, many park and estate remnants have been turned into golf courses, which could now provide a convenient source of harvestable acorns. Provisional Source Identified registration could be applied to these stands, pending assessment in ongoing comparative trials, as is at present being initiated in collaboration with the Tree Improvement Section of Coillte R&D, funded by COFORD.

The two issues of stem quality and acorn productivity are both important. The best-performing provenances should be preferentially harvested and these areas should be managed for seed production. Similarly, poor-performing provenances should be avoided. However, in practice, Killarney Tomies (KYT) has yielded several tonnes of acorns in mast-years (1995 and 2000), while Lough Gill (LGL), being limited in extent and heavily browsed by deer, produced less than 50 kg of harvestable material in 2000, a sessile oak mast-year throughout much of the island. Again, should, for example, the material from the Lough Gill (LGL), and Gort (GRT) provenances be reserved for commercial forestry and what could be done to improve the potential for seed harvesting in these stands? Indeed, is the material from Tomies Wood good enough for commercial afforestation or should it be reserved for the Native Woodland Scheme? Is it sufficient for the Forest Service Native Woodland Scheme that native acorns are supplied, or should the better performing provinces be stipulated? Although the overall objective of the scheme is to plant trees from native sources, it may be worth using native sources that have produced good quality progeny, particularly as wood production may assume a higher priority in the future with diminishing hardwood supplies from elsewhere.

There is at present little natural regeneration of oak in Ireland. Causes for the failure of natural regeneration are multiple, and include poor seed production, seed predation by birds, small and large mammals (Ashby 1959, Mellanby 1968, Shaw 1968), poor light conditions (Watt 1919), failure to germinate, and subsequent browsing of seedlings (Mellanby 1968). A 25-year study at Tomies Wood in Killarney National Park (Kelly 2002) determined that, while many seedlings germinated and survived for up to two years after a mast year, none survived outside enclosures largely as a result of predation by sika deer (*Cervus nippon* Temminck). In addition, low light levels under both the oak canopy and holly (*Ilex aquifolium* L.) understorey were responsible for the death of older oak volunteers and prevented recruitment. In order to facilitate natural regeneration the following conditions are required:

1. a mast seed year,
2. seed protected from predation,
3. a clean forest floor,
4. seed must be buried without being damaged,
5. sufficient light,
6. protection from browsing, and
7. vegetation control for at least five years to allow the seedlings to develop free of shading, water and nutrient competition and aggressive over-topping.

In short, in the case of oak, the difficulties and expense of natural regeneration may be an inexcusable waste of a limited seed resource (Peniston 1974).

Apart from extensive areas such as Charleville Estate, and the Glengarriff and Killarney National Parks, most registered seed stands are limited in area. While no stands are at present managed for seed production, appropriate silvicultural and land management practices could greatly improve productivity and should be seriously considered, in order to reduce dependency on imported seed and planting stock.

The potential for oak seed orchards is limited because of the long lead-in time prior to optimum production (30 to 40 years) together with low unit area production. However, a limited seedling seed orchard has been established at Ballyhea in Co Cork under the auspices of the British and Irish Hardwood Improvement Programme (BIHIP). It includes progeny from plus trees selected throughout Belgium, Britain, northern France and Ireland, although the Irish contribution to the orchard was limited by poor harvests during the collection period.

While acorns are recalcitrant seeds, recent developments in seed technology have given rise to increased storage time potential without a serious reduction in germination rate. Although the occurrence of mast-years is unreliable, in the event of a mast-year surplus acorns could be nursery sown the first year and the seedlings 'conditioned' (undercut and topped). Evans (1984) indicates that short sturdy plants produced this way ('stored') over 4 to 5 years will still grow vigorously when planted.

The native oak provenance trials assessed in this study are at present in an early stage in their life cycle. Now free of competing vegetation, canopy is beginning to close, and these trials now provide an opportunity for further research and comparative analyses, and also begin to fulfil their role as vital gene banks. These developing woodlands are a credit to those far-sighted foresters who conceived and undertook their establishment.

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Appendix 1. Oak provenances: locations, species groups and replication of provenances in the four trials.

Provenance	*Code*	*Source forest*	*County*	*Species group*	*CAM*	*DUR*	*BEL*	*DON*
					Number of replications			
Abbeyleix	*ABX*	*Abx. Estate*	*Laois*	*Ped*	*3*	*3*	-	-
Ballinahinch	*BAL*	*Derryclare*	*Galway*	*NW Sess*	-	-	*3*	*4*
Ballyvourney	*BVY*	*St. Gobnets*	*Cork*	*SW Sess*	*3*	*3*	*3*	*4*
Cahir	*CHR*	*Cahir Park*	*Tipperary*	*Ped*	*3*	*3*	-	-
Charleville	*CHI*	*Island*	*Offaly*	*Ped*	*3*	*3*	*3*	*4*
Charleville	*CHM*	*Main*	*Offaly*	*Ped*	*2*	-	-	-
Collooney	*COL*	*Collooney*	*Sligo*	*NW Sess*	*3*	*3*	*3*	-
Cootehill	*COO*	*Dartry*	*Monaghan*	*Ped*	*3*	*3*	*3*	-
Corrakyle	*COR*	*Caher N.Res.*	*Clare*	*NW Sess*	*3*	*3*	-	-
Croagh Patrick	*CPT*	*Brackloon*	*Mayo*	*NW Sess*	*3*	*3*	-	-
Delgany	*DLG*	*Glen of Downs*	*Wicklow*	*SE Sess*	*3*	-	-	-
Doolough	*DOO*	*Old head*	*Mayo*	*NW Sess*	-	-	*3*	*4*
Enniskerry	*ESK*	*Knocksink*	*Wicklow*	*SE Sess*	*3*	*3*	-	-
Foxford	*FOX*	*Pontoon*	*Mayo*	*NW Sess*	*3*	*3*	*3*	*3*
Glendalough	*GDL*	*Glendalough*	*Wicklow*	*SE Sess*	*2*	-	-	-
Glengarriff	*GRF*	*Bantry Desm.*	*Cork*	*SW Sess*	*2*	-	-	-
Glenealy	*GLY*	*Deputy's Pass*	*Wicklow*	*SE Sess*	*3*	-	-	*4*
Gort	*GRT*	*Coole*	*Galway*	*Ped*	*3*	*3*	*3*	*4*
Kenmare	*KNM*	*Uragh*	*Kerry*	*SW Sess*	*3*	*3*	*3*	*4*
Killarney	*KYT*	*Tomies*	*Kerry*	*SW Sess*	*3*	*3*	-	-
Killarney	*KYD*	*Derrycunnihy*	*Kerry*	*SW Sess*	*3*	-	-	*4*
Knocktopher	*KPH*	*Clone*	*Kilkenny*	*Ped*	*3*	*3*	*3*	-
Letterkenny	*LTK*	*Ballyar*	*Donegal*	*NW Sess*	*3*	*3*	*3*	*4*
Lough Gill	*LGL*	*Cullentra*	*Sligo*	*NW Sess*	*3*	*3*	*3*	-
Mulroy	*MUL*	*Rathmullen*	*Donegal*	*NW Sess*	*3*	*3*	*3*	-
Rathdrum	*RTH*	*Clara Vale*	*Wicklow*	*SE Sess*	*3*	*3*	*2*	-
Shelton	*SHL*	*Killeagh*	*Wicklow*	*SE Sess*	*3*	-	-	-
Waterville	*WTV*	*Waterville*	*Kerry*	*SW Sess*	*3*	-	-	*4*
Woodford	*WFD*	*Pollnaknockaun*	*Galway*	*NW Sess*	*3*	*3*	*2*	-

(Sources: Anon 1988 and Felton 2002)

Appendix 2. Survival: Provenance mean percentage survival rates and Z-scores by trial and for all trials combined. The two right-most columns contain the provenances sorted by overall mean Z-score, in descending order.

Trial	*CAM*		*DUR*		*BEL*		*DON*		*Mean*	*Provenance rating by Z-score*	
Provenance	*%*	*Z-score*	*%*	*Z-score*	*%*	*Z-score*	*%*	*Z-score*	*Z-score*		
ABX	*85.6*	*-0.4*	*81.1*	*-2.0*					*-1.4*	**GRF*	*1.9*
BAL					*88.9*	*0.8*	*86.7*	*0.7*	*0.8*	*LGL*	*0.9*
BVY	*88.9*	*0.2*	*85.6*	*-1.1*	*88.9*	*0.8*	*81.1*	*0.3*	*0.2*	*CHI*	*0.9*
CHR	*100.0*	*1.9*	*88.9*	*-0.3*	*92.2*	*1.1*	*88.3*	*0.8*	*1.1*	*BAL*	*0.8*
CHI	*78.9*	*-1.4*							*-1.4*	*RTH*	*0.6*
CHM	*88.9*	*0.2*	*85.6*	*-1.1*					*0.3*	**GDL*	*0.3*
COL	*77.8*	*-1.5*	*92.2*	*0.4*	*70.0*	*-0.9*			*-0.8*	*MUL*	*0.3*
COO	*92.2*	*0.7*	*96.7*	*1.3*	*63.3*	*-1.5*			*-0.1*	*KPH*	*0.2*
COR	*85.6*	*-0.4*	*92.2*	*0.4*					*-0.2*	**SHL*	*0.2*
CPT	*92.2*	*0.7*	*85.6*	*-1.1*					*0.4*	*COO*	*0.2*
DLG	*85.6*	*-0.4*							*-0.4*	*ESK*	*0.2*
DOO					*66.7*	*-1.2*	*88.9*	*0.8*	*-0.2*	*KNM*	*0.2*
ESK	*81.1*	*-1*	*96.7*	*1.3*					*-0.1*	*GRT*	*0.1*
FOX	*77.8*	*-1.5*	*92.2*	*0.4*	*85.6*		*44.4*	*-1.9*	*-0.5*	*BVY*	*0.1*
GDL	*90.0*	*0.3*							*0.3*	*COR*	*0.0*
GRF	*88.9*	*0.2*					*66.7*	*-0.5*	*-0.2*	*GLY*	*-0.2*
GLY	*100.0*	*1.9*							*1.9*	*CPT*	*-0.2*
GRT	*81.1*	*-1*	*88.9*	*-0.3*	*85.6*	*0.5*	*94.4*	*1.1*	*0.2*	*DOO*	*-0.2*
KNM	*96.7*	*1.4*	*88.9*	*-0.3*	*85.6*	*0.5*	*58.9*	*-1*	*0.1*	*LTK*	*-0.2*
KYT	*88.9*	*0.2*	*88.9*	*-0.3*	*88.9*	*0.8*			*-0.3*	*WDF*	*-0.2*
KYD	*88.9*	*0.2*					*61.1*	*-0.9*	*-0.4*	*KYD*	*-0.4*
KPH	*85.6*	*-0.4*	*88.9*	*-0.3*					*-0.2*	*KYT*	*-0.4*
LTK	*92.2*	*0.7*	*100.0*	*2.0*	*81.1*	*0.1*			*0.0*	**DLG*	*-0.4*
LGL	*74.4*	*-2.1*	*88.9*	*-0.3*	*85.6*	*0.5*	*94.4*	*1.1*	*0.1*	*CHR*	*-0.5*
MUL	*92.2*	*0.7*	*88.9*	*-0.3*	*85.6*	*0.5*			*0.3*	*WTV*	*-0.5*
RTH	*88.9*	*0.2*	*96.7*	*1.3*	*82.2*	*0.2*			*0.6*	*COL*	*-0.7*
SHL	*88.9*	*0.2*							*0.2*	*FOX*	*-1.0*
WTV	*95.6*	*1.2*	*92.2*	*0.4*	*54.4*	*-2.3*			*-0.4*	*ABX*	*-1.2*
WFD	*85.6*	*-0.4*					*66.7*	*-0.5*	*-0.5*	**CHM*	*-1.4*

** Provenance present at one trial only.*

Appendix 3. Height: Best 3 (B3) mean heights (in m) and Z-score by trial and for all trials combined. The two right-most columns contain the provenances sorted by overall mean Z-score, in descending order.

Trial	*CAM*		*DUR*		*BEL*		*DON*		*Mean*	*Provenance rating by Z-score*	
Provenance	*Height*	*Z-score*	*Height*	*Z-score*	*Height*	*Z-score*	*Height*	*Z-score*	*Z-score*		
ABX	*5.6*	*0.1*	*6.4*	*-0.7*					*-0.3*	*LGL*	*1.4*
BAL					*5.4*	*-0.2*	*3.5*	*0.4*	*0.0*	*ESK*	*1.2*
BVY	*5.1*	*-0.9*	*6.9*	*0.2*	*5.6*	*0.3*	*3.5*	*0.4*	*0.2*	*GRT*	*1.0*
CHI	*5.2*	*-0.7*	*6.6*	*-0.3*	*5.2*	*-0.8*	*4.3*	*1.6*	*-0.1*	*COR*	*0.8*
CHM	*5.1*	*-0.9*							*-0.9*	*FOX*	*0.6*
CHR	*5.3*	*-0.5*	*6.0*	*-1.6*					*-1.0*	*RTH*	*0.5*
COL	*5.0*	*-1.1*	*6.5*	*-0.6*	*5.2*	*-0.8*			*-0.8*	*MUL*	*0.4*
COO	*5.7*	*0.3*	*7.4*	*1.1*	*5.3*	*-0.5*			*0.3*	*COO*	*0.3*
COR	*6.0*	*1.0*	*7.1*	*0.5*					*0.7*	*KYD*	*0.2*
CPT	*5.4*	*-0.3*	*6.7*	*-0.1*					*-0.2*	*KPH*	*0.1*
DLG	*4.7*	*-1.8*							*-1.8*	*WTV*	*0.1*
DOO					*5.3*	*-0.5*	*3.5*	*0.4*	*-0.1*	*BVY*	*0.0*
ESK	*6.6*	*2.3*	*6.9*	*0.1*					*1.2*	*CHI*	*-0.1*
FOX	*6.0*	*1.0*	*7.4*	*1.1*	*6.1*	*1.7*	*2.4*	*-1.3*	*0.6*	**GDL*	*-0.1*
GDL	*5.5*	*-0.1*							*-0.1*	**SHL*	*-0.1*
GLY	*6.0*	*1.0*					*2.3*	*-1.4*	*-0.2*	*DOO*	*-0.1*
GRF	*4.8*	*-1.6*							*-1.6*	*CPT*	*-0.2*
GRT	*5.8*	*0.6*	*7.6*	*1.4*	*5.8*	*0.9*	*4.0*	*1.1*	*0.9*	*GLY*	*-0.2*
KNM	*5.4*	*-0.3*	*6.3*	*-0.9*	*5.1*	*-1.1*	*2.3*	*-1.4*	*-0.9*	*CPT*	*-0.2*
KPH	*5.4*	*-0.3*	*7.2*	*0.7*	*5.4*	*-0.2*			*0.1*	*ABX*	*-0.3*
KYD	*5.6*	*0.1*					*3.4*	*0.2*	*0.2*	*WDF*	*-0.3*
KYT	*5.2*	*-0.7*	*6.1*	*-1.3*					*-1.0*	*LTK*	*-0.3*
LGL	*6.4*	*1.8*	*7.4*	*1.1*	*5.9*	*1.2*			*1.4*	*COL*	*-0.8*
LTK	*5.1*	*-0.9*	*6.2*	*-1.1*	*5.8*	*0.9*	*3.1*	*-0.2*	*-0.4*	*KNM*	*-0.9*
MUL	*6.2*	*1.4*	*6.0*	*-1.6*	*6.0*	*1.4*			*0.4*	**CHM*	*-0.9*
RTH	*6.0*	*1.0*	*7.4*	*1.1*	*5.3*	*-0.5*			*0.5*	*KYT*	*-1.0*
SHL	*5.5*	*-0.1*							*-0.1*	*CHR*	*-1.0*
WDF	*5.4*	*-0.3*	*7.3*	*0.9*	*4.9*	*-1.6*			*-0.3*	**GRF*	*-1.6*
WTV	*5.5*	*-0.1*					*3.4*	*0.2*	*0.0*	**DLG*	*-1.8*

** Provenance present at one trial only.*

Appendix 4. Diameter: Best 3 (B3) mean dbh values (in cm) and Z-score by trial and for all trials combined. The two right-most columns contain the provenances sorted by overall mean Z-score, in descending order.

Trial	*CAM*		*DUR*		*BEL*		*DON*		*Mean*	*Provenance rating by Z-score*	
Provenance	*dbh*	*Z-score*	*dbh*	*Z-score*	*dbh*	*Z-score*	*dbh*	*Z-score*	*Z-score*		
ABX	*8.1*	*2.1*	*6.0*	*-0.1*					*1.0*	*ABX*	*1.0*
BAL					*6.3*	*-0.2*	*4.9*	*0.6*	*0.2*	*FOX*	*0.9*
BVY	*6.3*	*0.0*	*5.6*	*-0.6*	*6.0*	*-0.9*	*5.4*	*1.0*	*-0.1*	*KPH*	*0.8*
CHI	*6.2*	*-0.1*	*6.7*	*0.7*	*6.3*	*-0.2*	*5.5*	*1.1*	*0.4*	**GDL*	*0.8*
CHM	*6.5*	*0.2*							*0.2*	*GRT*	*0.7*
CHR	*6.4*	*0.1*	*4.8*	*-1.6*					*-0.7*	*WTV*	*0.6*
COL	*5.9*	*-0.5*	*6.1*	*-0.1*	*6.1*	*-0.7*			*-0.4*	*KYD*	*0.6*
COO	*7.1*	*0.9*	*6.5*	*0.4*	*6.4*	*-0.2*			*0.4*	*COO*	*0.4*
COR	*6.6*	*0.3*	*6.4*	*0.4*					*0.4*	*COR*	*0.4*
CPT	*5.7*	*-0.7*	*6.1*	*0.0*					*-0.4*	*CHI*	*0.3*
DLG	*5.4*	*-1.0*							*-1.0*	*MUL*	*0.2*
DOO					*5.9*	*-1.1*	*4.9*	*0.6*	*-0.2*	*LGL*	*0.2*
ESK	*6.7*	*0.5*	*6.0*	*-0.1*					*0.2*	*ESK*	*0.2*
FOX	*7.6*	*1.5*	*7.6*	*1.7*	*7.2*	*1.5*	*2.6*	*-1.4*	*0.8*	*BAL*	*0.2*
GDL	*7.0*	*0.8*							*0.8*	**CHM*	*0.2*
GLY	*6.6*	*0.3*					*2.8*	*-1.3*	*-0.5*	*RTH*	*0.0*
GRF	*4.6*	*-2.0*							*-2.0*	*BVY*	*-0.1*
GRT	*5.6*	*-0.8*	*6.9*	*0.9*	*7.6*	*2.2*	*5.0*	*0.7*	*0.7*	**SHL*	*-0.2*
KNM	*6.9*	*0.7*	*4.7*	*-1.7*	*5.6*	*-1.6*	*2.4*	*-1.6*	*-1.1*	*DOO*	*-0.3*
KPH	*6.9*	*0.7*	*7.6*	*1.8*	*6.4*	*0.0*			*0.8*	*CPT*	*-0.4*
KYD	*6.9*	*0.7*					*4.7*	*0.4*	*0.6*	*WDF*	*-0.4*
KYT	*5.6*	*-0.8*	*5.1*	*-1.3*					*-1.0*	*COL*	*-0.4*
LGL	*5.5*	*-0.9*	*7.0*	*1.1*	*6.7*	*0.5*			*0.2*	*GLY*	*-0.4*
LTK	*4.5*	*-2.1*	*5.4*	*-0.9*	*6.3*	*-0.2*	*4.0*	*-0.2*	*-0.9*	*CHR*	*-0.7*
MUL	*6.7*	*0.5*	*5.4*	*-0.8*	*7.0*	*1.1*			*0.2*	*LTK*	*-0.9*
RTH	*6.5*	*0.2*	*6.4*	*0.4*	*6.2*	*-0.5*			*0.0*	*KNM*	*-1.0*
SHL	*6.1*	*-0.2*							*-0.2*	*KYT*	*-1.0*
WDF	*5.0*	*-1.5*	*6.0*	*-0.1*	*6.7*	*0.5*			*-0.4*	**DLG*	*-1.0*
WTV	*7.3*	*1.1*					*4.3*	*0.1*	*0.6*	**GRF*	*-2.0*

** Provenance present at one trial only.*

Appendix 5. Stem form: Best 3 (B3) straightness, apical dominance and forking height mean Z-scores for all trials combined, and overall mean stem form Z-score. The two right-most columns contain the provenances sorted by overall mean Z-score, in descending order.

Provenance	Straightness	Apical dominance	Forking	Mean	Provenance rating by Z-score	
ABX	-0.5	-0.9	-0.9	-1.0	CHM*	0.8
BAL	-2.5	-0.3	0.1	-0.5	GDL*	0.6
BVY	-0.9	0.0	-0.8	-0.4	DLG*	0.4
CHI	-0.6	0.4	-0.2	0.1	WTV	0.4
CHM	0.4	1.7	1.0	1.0	LGL	0.3
CHR	0.3	-0.7	-0.3	-0.4	COO	0.3
COL	-0.1	0.4	-0.9	-0.2	KYD	0.3
COO	0.9	0.3	0.0	0.4	MUL	0.2
COR	1.6	-0.3	0.0	0.2	LTK	0.1
CPT	0.7	0.3	-0.2	0.1	GRT	0.1
DLG	0.0	2.1	0.4	0.8	COR	0.0
DOO	-1.9	0.9	-0.8	-0.1	CPT	0.0
ESK	-0.1	-0.1	0.6	0.0	CHI	-0.1
FOX	-0.7	-0.1	0.2	-0.1	ESK	-0.1
GDL	2.7	-0.2	0.0	0.8	GLY	-0.1
GLY	-0.8	-0.4	0.2	0.0	FOX	-0.1
GRF	-0.8	1.7	-1.6	-0.3	KYT	-0.2
GRT	-0.3	0.2	0.3	0.3	WDF	-0.2
KNM	-0.9	-0.2	0.2	-0.2	DOO	-0.3
KPH	-0.3	-1.7	-0.5	-0.8	KNM	-0.3
KYD	-1.0	-0.2	0.9	0.4	COL	-0.4
KYT	0.3	-0.2	0.2	-0.1	GRF*	-0.3
LGL	0.7	0.0	1.2	0.6	SHL*	-0.3
LTK	-0.1	0.4	0.2	0.3	CHR	-0.4
MUL	0.3	0.6	0.2	0.3	BVY	-0.4
RTH	0.0	-0.8	-0.6	-0.5	BAL	-0.5
SHL	-0.8	-0.2	0.2	-0.3	RTH	-0.5
WDF	0.4	-0.4	-0.2	-0.1	KPH	-0.8
WTV	-0.2	-0.2	1.7	0.8	ABX	-1.0

* *Provenance present at one trial only.*

Juvenile wood in Irish grown Sitka spruce and the impact of rotation length

Áine Ní Dhubháin[a] Donal Magner[b] and Maarten Nieuwenhuis[a]

Abstract

The impact of rotation length on the level of juvenile wood in Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in Ireland was investigated. Mean density was 539 kg/m^3 at the first growth ring, rising to 558 kg/m^3 in the second, and thereafter declining to 384 kg/m^3. Demarcation between juvenile and mature wood was assumed to occur at growth ring 14, where the mean density was lowest. The proportion of juvenile wood was then estimated for Sitka spruce of yield class 24, and was found to substantially decline with age, from 30.3% at age 30 to 13.7% by age 46 (tabulated age of maximum mean annual increment). The implications of the results for rotation length policy are discussed.

Keywords: Juvenile wood, wood density, rotation length, timber quality, Sitka spruce.

Introduction

Introduced to Ireland in 1835 (Joyce and OCarroll 2002), Sitka spruce (*Picea sitchensis* (Bong.) Carr.) accounts for over 60% of the area of the forest estate. In Coillte (the commercial state forestry company) plantations, the species has a mean yield class of 17 $m^3ha^{-1}an^{-1}$ (Horgan et al. 2003). The improvement in the quality of land afforested in Ireland since 1990 has meant that the predicted yield class of Sitka spruce planted since then exceeds 18 $m^3ha^{-1}an^{-1}$ and sites more recently planted by Coillte have an average yield class of 20 $m^3ha^{-1}an^{-1}$ (ibid). As it has proved to be a highly versatile and productive species, it is likely that Sitka spruce will remain the principal softwood species in Ireland.

The very fast rate of growth of Sitka spruce has lead to the species being grown to very short rotations. For example, it is the general practice within Coillte and most of the private sector to clearfell Sitka spruce at 80% of the age of maximum mean annual volume increment (MMAI). More recently forestry investment companies have advocated 30-year rotations which represent a further reduction in the age of MMAI (Anon. 2000).

The fast growth rate of the species, coupled with short rotations leads to high proportions of juvenile wood (Mitchell and Denne 1997). Juvenile wood, which is the wood located closest to the central part of a conifer stem, differs considerably from mature wood (Panshin and de Zeeuw 1980). The properties of juvenile wood are generally regarded as inferior to those of mature wood (Larson 1969; Harvald and Olesen 1987; Zobel and van Buijtenen 1989). These include large microfibril angles, short tracheids, high longitudinal shrinkage during drying (Zobel 1975) and, in some

[a] UCD School of Biology and Environmental Science, University College Dublin, Belfield, Dublin 4, Ireland. (corresponding author, aine.nidhubhain@ucd.ie).

[b] Secretary Wood Marketing Federation, 1 Heatherbrook, Marlton Road, Wicklow.

species, lower density (Walker and Nakada 1999). The combination of these properties means that juvenile wood usually has poor strength, with reductions of over 100% recorded in modulus of elasticity and modulus of rupture in juvenile compared with mature wood of loblolly pine (McAlister and Clark 1991). The large microfibril angle in juvenile wood coupled with its tendency to exhibit spiral grain also renders it unstable (Zobel and Sprague 1998).

The timber of Sitka spruce is suitable for a wide variety of end-uses such as structural material, fencing, palletwood and pulpwood and is the mainstay of the current wood processing industry in Ireland (DAFF 1996). There has been concern however, that the strength properties of much of this plantation-grown Sitka spruce may be on the borderline of acceptability for structural performance (Mitchell and Denne 1997).

This paper describes a study on juvenile wood in Irish grown Sitka spruce. The objectives of the study were to:

a) identify the juvenile wood zone in Sitka spruce;
b) use this information to determine the impact of rotation length on the proportion of juvenile wood in a final crop.

Background

Although juvenile wood is present in all trees, the extent of the juvenile wood zone varies, depending on species and environmental factors. Haygreen and Bowyer (1982) applied the term juvenile wood to the wood found in the first 5-25 growth rings. Walker and Nakada (1999) indicate that for radiata pine (*Pinus radiata*) and sugi (*Cryptomeria japonica*) from plantation forests, it is convenient to refer to the first 10 growth rings as juvenile wood. Cown (1992) also defined juvenile wood in radiata pine as the wood within 10 growth rings of the pith. The juvenile wood zone in Sitka spruce is considered by Mitchell and Denne (1997) to include the nine growth rings from the pith while Brazier and Mobbs (1993) referred to the first 12 growth rings from pith as juvenile wood. However, there is no clear demarcation line between juvenile and mature wood because wood properties change gradually, often taking place over a number of years, which form a transition zone (Zobel and Sprague 1998). Furthermore, the location and extent of the transition zones differs for the different wood properties such as density, microfibril angle and tracheid length. In the case of loblolly pine (*Pinus taeda* L.), Szymanksi and Tauer (1991) reported that the transition period between juvenile wood and mature wood can last six years, while Zobel and van Buijtenen (1989) believed it to be five years.

Despite the difficulties associated with identifying the exact extent of the juvenile wood zone, a number of researchers have attempted to do so. Most commonly, density differences have been used to define the juvenile wood zone (Zobel and van Buijtenen 1989). For example, for Sitka spruce, Evertsen (1988) estimated the demarcation line between juvenile wood and mature wood to be the 16th growth ring from the pith, while Schaible and Gawn (1989) estimated it to be the 12th ring.

In their work on loblolly pine, Loo et al. (1985) used regression analysis to determine the age of transition from juvenile wood to mature wood. This involved successively regressing density on age for 'juvenile' and 'mature' parts of the stem, based on an arbitrary cut-off point of age 4 and less for the juvenile zone, and greater than age four for the mature zone. This cut-off point was moved upwards in two-year intervals. The age of transition was estimated as the age at which the mature wood regression of density on age provided the best fit (defined as the smallest error sum of squares) (Loo et al. 1985). A similar approach was used by Szymanski and Tauer (1991).

Materials and methods

The study area

The trees selected were from a stand of pure Sitka spruce in a Coillte-owned forest in Co Wicklow. The stand was at an elevation of 175 m, on a free-draining acid brown earth, on a gently sloping, south-east facing site. The stand was planted in 1957 at 1.82 m spacing using a Washington seed origin. It was thinned in 1976 by removing one line in three. Subsequent selective thinnings were carried out in 1984 and 1996. The second thinning was delayed due to poor markets for pulpwood in the late 1970s and early 1980s. The estimated yield class (YC) for the stand was 24 m^3 $ha^{-1}an^{-1}$.

Sampling

In selecting trees for study, the aim was to choose trees as similar in height as possible. The estimated top height for a 42-year-old, YC 24 Sitka spruce stand is 29.5 m (Hamilton and Christie 1971). Nine trees whose heights were within 5% of this height were selected for study. Diameter at breast height ranged from 38.5 to 45.1 cm.

After the trees were identified and before they were felled, the northern and southern cardinal points and tree number were marked on the stem at breast height (1.3 m above ground level). Once the trees had been felled a 40 mm disk was cut from the stem at breast height. Disks were numbered from 1 to 9 and the north-south, west-east axes were marked on the upper face of each disk.

Density measurement

Disks were stored and room dried, from March to August, 2000. In addition, they were prepared for density measurements by planing the unmarked face of each disk. They were sent to the Forestry Commission, Northern Research Station at Roslin Scotland in September 2000 for density measurement.

Density was assessed using computer-aided tomography. The scanner used was a Siemens Somatom™ CR. The raw output of the scanner is in Hounsfield units. Nominal values of -1024 and 0 are representative of water and air respectively. Based on this calibration, the readings from the scanner were converted to kg/m^3. Each output picture from the scanner was interogated by a specially written computer programme in Mathcad®. The operator marked the position of the disk pith and slices were extracted across the disk in north-south and west-east directions. The programme then fitted a cubic spline to the individual data points, which were at 2 mm spacing. The peaks in the cubic spline fit were then determined and were regarded as the end of each growth period (latewood). The mean, maximum and minimum density between each peak, the distance between peaks (ring width) and the distance of the centre of the ring from the pith were established and the information from each of the slices exported to a spreadsheet ready for analysis and archiving.

Minimum, maximum and mean densities (kg/m^3) for each growth ring, for compass directions north-south and west-east, were recorded. In the results section that follows the data from the various compass directions are considered replications and are averaged for each growth ring. Only data from rings 1 to 26 were used, for two reasons:

1. densities fluctuated widely at the edges of the disks where the growth rings were narrow, leading to problems with the scanner resolution;
2. as some of the tree disks split on drying, it was not possible to record densities for all growth rings to the outermost ring. Thus in order to have a consistent number of readings for all of the disks, the number of growth rings used was confined to 26.

Determination of the extent of the juvenile wood zone

In order to consistently determine the point of demarcation between juvenile and mature wood the assumption was made that the point of demarcation between the two occurred at the ring number where the mean ring density reached a minimum. In order to objectively determine the ring of mean minimum ring density, a number of empirical regressions were fit to the combined tree data, based on polynomials in ring number. The regression that provided the best fit between density and ring number was chosen. The minimum value of the function (and its associated number of years) was then obtained by differentiation.

Impact of rotation length on percentage juvenile wood content in a stand of Sitka spruce (yield class 24)

To determine the influence of rotation length on juvenile wood content, three ages were chosen for Sitka spruce (yield class 24):

a) 30 years – the rotation length recommended for this yield class by groups managing forestry investment fund portfolios in Ireland (Anon. 2000);
b) 37 years – the rotation length which represents 80% of age of MMAI and is commonly used by Coillte for Sitka spruce;
c) 46 years – the rotation length which represents the age of MMAI.

The yield model with characteristics closest to the stand was selected: Yield Table 61, the yield table for YC 24 Sitka spruce, planted at 1.7 m spacing with intermediate thinning (Hamilton and Christie 1971). The top heights and mean diameter breast height (dbh) overbark values for a Sitka spruce stand at each of the rotations listed above were obtained. The yield table also gave a mean volume per tree for each of the three rotations under consideration. The dbh and volume estimates were then converted to underbark values using conversion factors outlined in Hamilton (1975). All calculations were based on the tabulated yield model data, with information from the sample used to indicate where the juvenile wood ended.

To estimate the volume of juvenile wood for each rotation, it was assumed that the juvenile wood zone was cylindrical. While some studies show that the juvenile wood zone tapers slightly from the base of the tree upwards, a number of studies which have examined proportions of juvenile wood to mature wood have used the simplifying assumption that the juvenile wood zone forms a cylindrical column with the pith as its centre (Walker and Butterfield 1995, Zobel and Sprague 1998). The juvenile wood cylinder was assumed to extend from the base of the tree to a top underbark diameter equal to the diameter of the juvenile wood zone. Thereafter the remaining wood in the tree was assumed to be juvenile to the top 7 cm diameter (Section 2, Figure 1). Yield Table 61 showed that the mean dbh for a YC 24 Sitka spruce stand at the age/ring number at which the juvenile wood zone ended - 14 years - was 10.8 cm overbark, 10.0 cm underbark (Section 1, Figure 1). Hamilton's tables (1975) gave the estimated height to the underbark diameter equal to the diameter of the juvenile wood zone and the height to 7 cm top diameter. The total volume of juvenile wood in the two sections was estimated from:

$$Volume = \frac{\pi D^2 h}{4} + \frac{\pi}{12}(D^2 + Dd + d^2)H$$

where
D = underbark diameter of the juvenile wood core (10 cm);
H = height from base of tree to point where diameter of tree is D;
d = diameter of top of frustum (7 cm);
h = height from point where diameter is D to point where diameter is d.

Results

The radial trend in density was estimated based on the nine sample disks. Density, when plotted against ring number from pith (Figure 2), declined from the second ring to rings 13–14, after which it rose slightly.

Mean density was regressed on polynomials in ring number, a good fit (R^2 96% $p \leq 0.0001$) was obtained using a three-degree model.

$$Mean\ density\ (MD)\ (kg/m^3) = 598.87 - 37.08(RN) + 2.06(RN^2) - 0.03(RN^3)$$

where:
RN = ring number;
RN^2 = square of the ring number;
RN^3= cube of the ring number.

The predicted density values for the ring numbers were plotted against the observed density values (Figure 2).

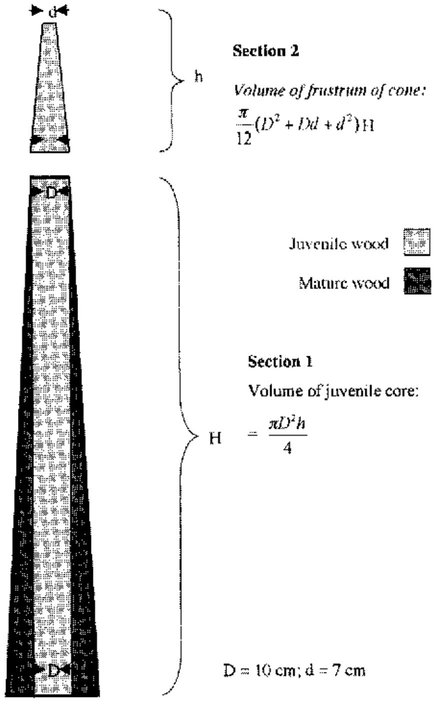

***Figure 1**: Assumptions made in calculating the amount juvenile wood Sitka spruce stems.*

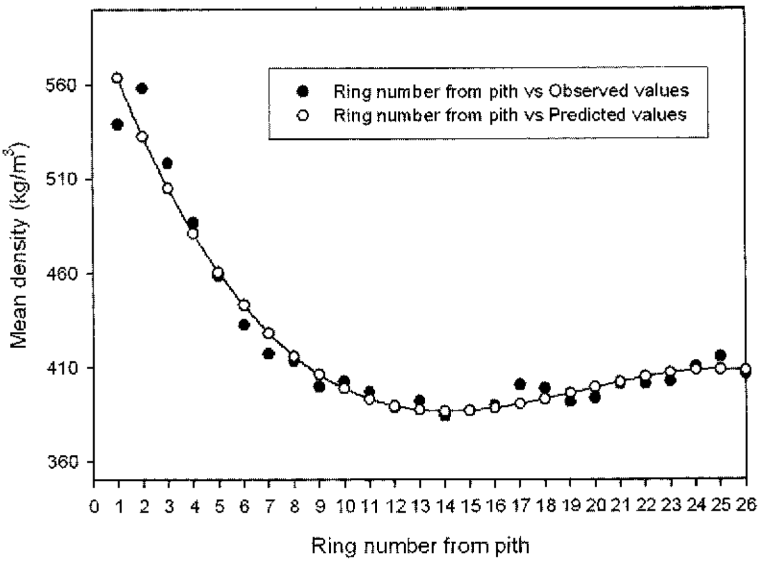

***Figure 2**: Observed and predicted mean density versus ring number.*

To determine the minimum point of the equation, the first derivative with respect to ring number was:

$$\frac{dMD}{dR} = -37.08 + 4.116RN - 0.10551\,RN^2$$

To obtain the minimum point on the curve the function was first set equal to zero. The roots were ring numbers 14.04 and 24.96. To confirm that 14.04 was the minimum point of the curve, the second derivative was found to be 3.905. As this value is positive it showed that 14.04 was the minimum point on the curve. This led to the result that the juvenile wood zone ended at ring 14 for the Sitka spruce examined.

Proportionate juvenile wood in Sitka spruce stands of varying ages

Using the approach outlined in Materials and methods, the total volume of juvenile wood per tree was calculated for the three rotations (Table 1).

The results show that the percentage of juvenile wood in a 30 year old Sitka spruce stand of yield class 24 was 30.3%. At 37 years it was 20.3%, while at 46 years the average juvenile wood content was 13.7%.

Discussion

To accurately assess trends in juvenile wood, all the main characteristics that define juvenile wood would need to be measured, in particular wood density, microfibril angle and fibre length. The scope of this study allowed for the measurement of only one property. Thus, wood density was chosen, because density trends have been most commonly used to define the juvenile wood zone (Zobel and van Buijtenen 1989). In addition, a rapid and reliable method was available to measure wood density.

The radial trend in density recorded in this study is in agreement with that recorded for Sitka spruce in other studies. Brazier (1967), O'Sullivan (1976), Harvald and Olesen (1987), Petty et al. (1990) and Mitchell and Denne (1997) all found high densities close to the pith in Sitka spruce. Specifically, Harvald and

***Table 1**. Percentage juvenile wood in Sitka spruce at three ages (yield class=24 $m^3\ ha^{-1}\ an^{-1}$).*

	ROTATION LENGTH YEARS		
	30	*37*	*46*
Top height (m)[1]	*22.0*	*26.5*	*31.0*
Mean dbh overbark (cm)[1]	*25.4*	*32.0*	*39.3*
Mean dbh underbark (cm)[2]	*24.3*	*30.7*	*37.8*
Mean tree volume underbark (m^3)[2]	*0.48*	*0.93*	*1.63*
Volume of juvenile wood per tree (m^3)	*0.15*	*0.19*	*0.22*
Juvenile wood (%)	*30.3*	*20.3*	*13.7*

[1] Hamilton and Christie (1971) [2] Hamilton (1975)

Olesen (1987) found, on one site in Denmark, that the "basic density decreased with increasing ring number until ring 17 where it seemed to stabilise" when measured in the tree at a height of 1.3 m. At another site, they found that the decrease in basic density ceased at rings 10-11, followed by an increase in density until stabilisation was reached between ring 16 and 25. Petty et al. (1990) found that, while density was approximately 400 kg/m^3 in the five growth rings close to the pith, the average density in rings 16 to 20 was approximately 350 kg/m^3. O'Sullivan (1976) found that density decreased to ring 10, reaching a minimum between ring 10 and 15, and gradually increased thereafter. In this study, wood density was found to be lowest at ring 14. In contrast, Mitchell and Denne (1987) suggested that the mature wood zone began at ring 10, Evertsen (1988) selected ring 16, while the point of demarcation between juvenile wood and mature wood was identified at growth ring 12 by Schaible and Gawn (1989).

The pith-outwards radial trend in density in Sitka spruce differs from that of many conifers. In general hard pines have a rather uniform pattern of low density at the pith, a rapidly increasing density through the juvenile period followed by a series of annual rings that have an essentially constant density, albeit fluctuating from year to year (Zobel and van Buijtenen 1989). In contrast, the general rule for *Abies, Picea* and *Tsuga* species is a high density near the pith with a decrease for some rings followed by a levelling off or a moderate increase toward the bark (ibid).

Regression analysis, combined with finding the minimum point of the function it provided, were used to demarcate the boundary between juvenile wood and mature wood in this study. While similar approaches have been elsewhere (Loo et al. 1985; Szymanski and Tauer 1991), we are not aware of the specific approach employed in this study having been used previously. In the study by Loo et al. (1985) of juvenile wood in loblolly pine, density data were regressed against age/ring number data to determine the end of the juvenile wood zone. Szymanski and Tauer (1991) used a similar approach to compare the age of transition from juvenile to mature wood specific gravity in provenances of loblolly pine.

The impact of rotation lengths on the percentage of juvenile wood in a Sitka spruce stand

The results show that there is a substantial difference in the proportion of juvenile wood in a Sitka spruce stand grown to different rotations. We estimate that a high yielding Sitka spruce stand, if felled at 30 years, will comprise about 30% juvenile wood. If felling is delayed for seven years or sixteen years the proportion of juvenile wood in the stand will be considerably lower at 20% and 14% respectively, with the amount of juvenile wood at 30 years over twice that at 46 years. This finding supports the view that extending rotation length is a way to improve overall wood quality (Brazier 1986; Simons Strategic Services Division 1991; Zobel and Sprague 1998). Indeed, Schaible and Gawn (1989) found in a study of the strength of timber from unthinned stands of Sitka spruce (YC 20 - 24) that if rotations were extended to a point where top height was greater than 19.3 m, the volume of juvenile wood as a percentage of total tree volume, could be reduced by an equivalent of 4-5% for every metre gained in top height. However, sawing method will strongly influence how much of the additional mature wood is converted to sawnwood. For example, where chipper canters are used it is likely that much of the mature wood will be chipped.

Conclusions

The debate on juvenile wood and wood quality has been underway for a considerable time in all countries with a strong dependence on fast growing plantations. Growers and processors in all regions acknowledge that juvenile wood is undesirable for products requiring stability and strength. Zobel and Sprague (1998) indicate that the presence of juvenile wood is especially critical to the quality of solid wood products. Indeed, Senft et al. (1985) argue that "unless accounted for in some manner, the effect of juvenile wood on strength and performance of future wood products could be disastrous". The issue of juvenile wood content is especially critical in Ireland because of the processing sector's reliance on fast-growing Sitka spruce. Even though the juvenile wood zone in Sitka spruce is denser on average that the mature wood zone, it shares the other quality-lowering features of juvenile wood from other species including large microfibril angle (Treacy et al. 2000) and short tracheids (Ward and Gardiner 1976).

Concerns regarding the quality of high yielding Sitka spruce were expressed in a report on the sawmilling industry in Ireland (Simons Strategic Services Division 1991). It also indicated, however, that high yielding Sitka spruce could provide excellent raw material for the sawmilling sector, provided that rotations were not excessively short. It also stated that the policy of using reduced rotations may satisfy the fibre and low quality sawlog market but will not bring Sitka spruce into the high quality end of the market.

Sawlog production and processing in Ireland need to be quality driven to increase domestic and export market share. The onus will be on sawmills to continue improving quality, which will need to be matched by an increase in quality of the raw material. This will be necessary to ensure that domestic sawlog material is in a position to compete with exports from countries such as Sweden, where 40% of all sawlogs are older than 100 years (Simons Strategic Services Division 1991). On the clear evidence that the presence of juvenile wood limits the end use potential of solid wood products, it is perhaps time to reconsider the policy of managing stands in Ireland for short rotations and consider reverting over time to forest rotation ages based on MMAI, or longer, with adjustments to these based on biological and environmental reasons.

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Stability of Sitka spruce on mole-drained and ploughed surface water gley soil

Michael Rodgers[a], James McHale[b] and John Mulqueen[c]

Abstract
A study compared the effects of two site preparation methods, double mouldboard ploughing and mole-drainage on the stability of Sitka spruce trees subjected to repeated and monotonic forced loads. The trees were planted on a low-permeability surface water gley soil in two experimental plots in the north-west of Ireland. The soil is highly productive with average Sitka spruce productivity in excess of 18 m^3 ha^{-1} yr^{-1}. However, the major constraint on production is windthrow, which is dependent on a number of factors, including soil preparation. Repeated loading tests were carried out on 6-metre tall truncated tree stems in both cultivation treatments using a specifically constructed tree rocker. During a repeated load test in the double mouldboard plot, pore water pressure increased under the root plate and fractured the soil causing a washout of fines. Once this fracturing occurred, the sway of the tree stem and, as a result, the overturning moment increased substantially, making the tree very unstable. When a repeated load test was carried out in the mole-drained plot, there was little build-up of pore water pressure even though the loading was greater than that applied to the tree stem in the mouldboard plot. Monotonic tests, which consisted of pulling six trees over in each plot, were used to calculate the trees' maximum overturning moments. In the double mouldboard ploughed plot, the repeated loading test clearly showed that soil failure can be initiated at much lower overturning moments than the maximum moment applied during monotonic pulling tests. Both the repeated and monotonic loading tests indicated that the trees planted in the mole-drained plot were substantially more stable than those planted in the double mouldboard plot.

Keywords: Windthrow, dynamic tests, Sitka spruce, mole-drainage, double mouldboard ploughing, pore water pressure, overturning moment.

Introduction
Windthrow is defined as the overturning of trees and their root plates during windy conditions. In Ireland, it was estimated that windthrow caused direct financial losses of €14 m during the period 1987-1997 (Hendrick, 1998). Windthrow can also lead to increased soil erosion, run-off and adverse visual impact. Windthrow is common worldwide, particularly in Ireland, the United Kingdom, Northern Europe, North America and New Zealand.

The occurrence of windthrow depends on tree species, root system configuration, harvesting methods (Flesch and Wilson 1999; Mitchell 2000), as well as a number of

[a] Department of Civil Engineering, National University of Ireland, University Road, Galway, Ireland (corresponding author, michael.rodgers@nuigalway.ie).

[b] Ryan Hanley Consulting Engineers, The Crescent, Galway, Ireland.

[c] Department of Civil Engineering, National University of Ireland, University Road, Galway, Ireland.

other factors, including soil type, soil drainage, soil strength, climate, elevation, aspect and location. In poorly drained wet soils, liquefaction and failure of the soil occurs (Rodgers et al. 1995) under the root plate during windthrow, and roots are pulled out of the ground. The level of windthrow can be reduced by lowering the water table using effective drainage, which also facilitates deep rooting (Mason and Quine 1995) resulting in increased resistance to roots being pulled out (Stokes et al. 1996).

In the past, the preferred method of drainage used in water surface gleys was double mouldboard (DMB) ploughing (Hendrick 1989). The furrow provided the drainage channel and the tree seedlings were planted in the plough ribbon. Although successful in terms of lowering the water table beside the furrow, the method fostered asymmetric root plates, by confining the root development to the overturned plough ribbon and the inter-furrow surface soil (Hendrick 1989). The result of such confinement is to make the trees vulnerable to damage when the wind blows from a direction at right angles to the direction of ploughing (Hamilton 1980).

Mechanical (or excavator) mounding is now the favoured method of site preparation where the trees are planted in small mounds of soil excavated from drains at approximately 12 m spacing. This method incorporates both cultivation and drain excavation in one operation. The mounds are typically 45 x 45 cm in area and 15 cm in height. Owing to the fact that it is only relatively recently that this technique has become widespread, little is known about the stability of trees established on mounds. The ability of the drains at 12 m centres to lower the water-table to a sufficient depth in impervious soils depends on the permeability of the soil (Mulqueen 1998). Wills et al. (2001) found that the mechanical mounding system only lowered the water-table for a distance of 3 m from the drain.

Mole drainage, which is suitable for many Irish soils but rarely used in forestry, comprises 75 mm diameter drains installed using a mole plough, about 450 mm below the ground surface at 1.0 - 2.0 m centres; the correct drain spacing depends on the permeability of the soil (Mulqueen et al. 1999), and the planting and thinning strategies. The plough consists of a frame with a mounted vertical narrow shaft, which carries at its bottom a cylindrical mole with an inclined leading edge that faces upwards (Mulqueen 1998). As the plough is pulled, the soil above the level of the mole is lifted and cracked. A cylindrical expander, which follows the mole, partially remoulds the soil to produce a self supporting tunnel drain. The soil cracking is of critical importance in increasing the permeability of the subsoil to the same order of magnitude as that of the topsoil (Rodgers et al. 2003). The cracks allow the rapid percolation of excess water to the mole drain thereby lowering the water table in the soil. Wills et al. (2001) found that mole drainage lowered the water-table uniformly across a suitable site, and may therefore be more effective in surface water gleys than mechanical mounding. The trees are normally planted beside the slot formed by the plough shaft.

A number of monotonic and dynamic testing studies have been carried out to examine the mechanisms of windthrow in coniferous forests. Monotonic testing is the more common form of testing due to its simplicity (Coutts 1986, Blackburn et al.

1988). However, since wind loading is dynamic, a more realistic insight into windthrow mechanisms is provided by dynamic forced loading tests.

Monotonic testing normally involves pulling trees over using a winching system. Displacements of the tree and pulling forces are measured during the test. Using these measured data, the applied overturning moments can be readily calculated. Monotonic analyses are useful when comparing the relative stability of trees planted in different soil types or drainage conditions (Hendrick 1989). Coutts (1986) conducted a series of monotonic tests on Sitka spruce trees planted on a peaty gley (wet mineral soils of low permeability that have developed under conditions of permanent or intermittent water logging). From these tests, he identified four major components of resistance to overturning: soil resistance, the windward roots acting in tension, the weight of the root plate, and the resistance to bending at a hinge on the root plate. Hendrick (1989) conducted a series of destructive monotonic tests on the truncated stems of Sitka spruce planted on two differently drained plots: on one plot, mole-drainage was used and on the other, spaced furrow ploughing. He found that the mean maximum overturning moment for the trees on the mole-drained plot was significantly higher than that for the trees on the furrow ploughed plot. This study also indicated that the root plates for the mole-drained trees were deeper and more radially symmetric that those for the furrow ploughed trees; the asymmetrical root systems of the furrow ploughed trees being caused by the truncating effect of the furrow. Blackburn et al. (1988) noted from a series of monotonic tests on Sitka spruce trees planted on a peaty gley that the load/displacement ratio of the tree system was reduced by a factor of 2-3 after soil failure had taken place. This reduction indicates that once the soil under the root plate of a tree has failed, increased displacements will occur for the same pre-failure wind load with a consequent increase in the overturning moment and likelihood of windthrow.

Rodgers et al. (1995) conducted repeated forced loading tests on 6 m high truncated stems of Sitka spruce trees planted on a peaty gley. Spaced furrow ploughing had been used to drain the soil and provide elevated planting positions. The repeated loading was carried out using a mechanical rocker, which was mounted on top of the truncated stem. Various responses of the test trees were monitored during the repeated loading tests, and included: the horizontal displacement of the stem, the strain along the stem at various heights, the pore water pressure at a depth of 400 mm below the surface of the root plate, and the vertical movement of the root plate. Results from this forced rocking experiment on a test tree showed that when the maximum overturning moment in a load cycle exceeded 7 kNm, there was a build-up in the soil pore water pressure. This build-up continued to increase to about 17 kPa, when hydraulic fracture of the soil occurred; the pore water pressure increase was accompanied by increases in the maximum cyclic displacements and overturning moments. Liquefaction of the soil was observed in the root plate and fines were pumped out through fractures in the soil surface. For another test tree, once the hydraulic fracturing took place, the movement of the tree stem changed from an oscillating motion in a single vertical plane to a loop motion in plan indicating that the natural frequency of the tree system had changed. When a reduced loading was later applied to the tree, its movement reverted to its oscillating motion with larger displacements, indicating that once soil failure has occurred, a tree can be swayed by less external energy after failure than before. It was considered that possible failure of the tree had been initiated when there was a substantial increase in the pore water pressure build-up. The overturning moment required to initiate failure using the tree rocker on the spaced furrow ploughed plot was considerably lower than the maximum overturning moment found from monotonic pulling tests conducted on intact neighbouring trees. A complete tree was also instrumented on the same site and its response to windy conditions was remotely monitored. In a storm, pore water pressures under the root-plate of 9 kPa and overturning moments of 7 kNm were measured, indicating that the tree rocker experiments produced realistic data on the dynamic behaviour of trees and their root plates during storms.

This paper compares the performances of 27-year-old Sitka spruce planted on a low-permeability surface water gley soil in two experimental plots when they were subjected to both monotonic and repeated forced loading tests; one plot had been cultivated using double mouldboard ploughing and the other was mole-drained. The objective of the study was to establish if mole-drainage was likely to increase the stability of Sitka spruce and reduce the losses caused by windthrow.

Site and soil characteristics

The testing was conducted in the northwest of Ireland at Ballyfarnon Forest, Co Sligo, which was planted with Sitka spruce in 1971. The forest lies, for the most part, on the slopes of one of a number of drumlins, the dominant topographical feature in the area. The parent material of these drumlins consists of a very sticky glacial till derived mainly from middle limestone (calp), upper Carboniferous limestone, Ordovician and Silurian shale, Coal measure shale, and Millstone shale (An Foras Talúntais 1980). The soil is highly productive with an average Sitka spruce yield in excess of 18 m^3 ha^{-1} yr^{-1} (Hendrick 1999). However, the major constraint on production is windthrow, which is dependent on a number of factors, including soil preparation. The area in which the forest is located has an average annual rainfall of approximately 1300 mm and experiences a mean annual wind speed of 4-5 m s^{-1}. The maximum gust speed likely to be exceeded once in fifty years is about 48 m s^{-1}. Some windthrow had occurred within the forest but none was observed within the test plots. The top mean height of the forest at the time of testing was approximately 16.5 m.

The topsoil at the site is 100-200 mm thick and is underlain by a silty sandy clay or surface water gley subsoil with a very low permeability. The top layers of undrained soils at the site are frequently saturated, mainly in late autumn through early spring. As a result, the roots of Sitka spruce trees in uncultivated soil are very shallow, since they can only survive in unsaturated conditions. The constituents of the subsoil, excluding gravel, were silt (27.2 %), sand (29.6 %) and clay (40.7 %). The average natural moisture content (w_n) of the undrained subsoil was 31.5 %. Its liquid limit and plasticity indices were 52.8 %, and 24.9 %, respectively. The average undrained shear strength of the soil, from fall cone tests, was 135 kPa. The hydraulic conductivity (K) of this soil type is approximately 7 x 10-10 m/s (Mulqueen 1998). From these details, the soil from the test site can be classified as a firm to stiff, silty sandy clay of intermediate to high plasticity (B.S. 5930: 1981), with a very low permeability.

A multi-point mercury manometer tensiometer was installed in the mole-drained plot and in an undrained test plot at a distance of 0.35 m from the trees to monitor the hydraulic potential of the soil at various depths. Figure 1 presents the results from both plots following dry and wet periods. The depths of the water table below ground surface occur where the hydraulic potential crosses the gravitational potential line. For the dry period, the water table depths were 0.6 m in the undrained plot and 0.8 m in the mole-drained plot; for the wet period, the water table depths were 0.2 m for the undrained plot and 0.4 m for the drained plot. These depths clearly show that the mole-drains were effective in lowering the water table.

Methods

Monotonic testing was carried out using a winching system that comprised a wire rope, a winch and a load cell. The load cell operated in tension only and was designed to measure tensile forces up to 10 kN. The system is illustrated in Figure 2. The trees were truncated at a height of 6 m. One end of the wire rope was attached to the top of the truncated stem and the other end to the winch. The load cell was then connected between the winch and an anchor tree.

The tree rocking device consisted of two disks with eccentric masses, which were rotated in opposite directions by a hydraulic motor through gears, chains and sprockets. A vertical elevation of the rocker is illustrated in Figure 3 and its operating principle is shown in Figure 4. A hydraulic pump, which was driven by a petrol engine, activated the motor. The tree rocker was mounted and clamped on the

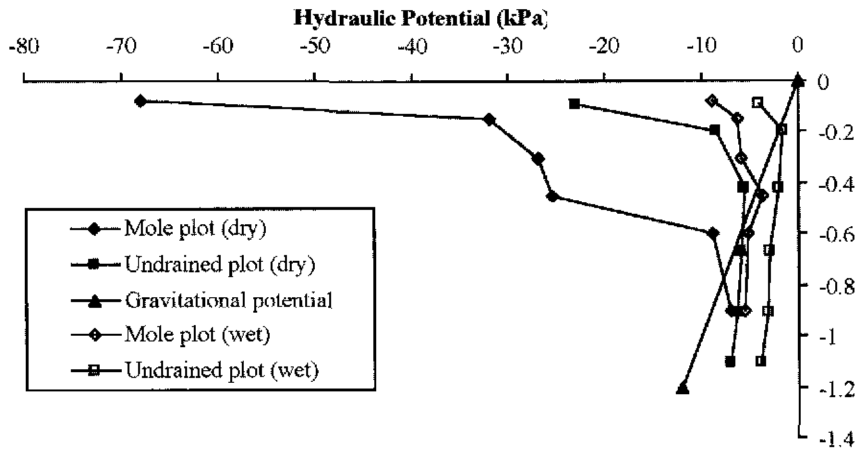

Figure 1: Variation in hydraulic potential between mole-drained and undrained plots at Ballyfarnon during dry and wet periods.

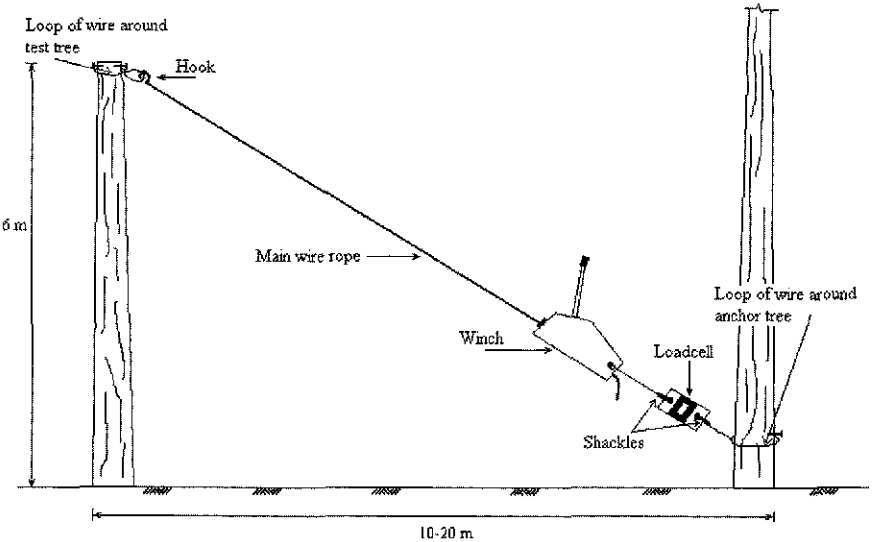

Figure 2: Destructive monotonic tree pulling arrangement.

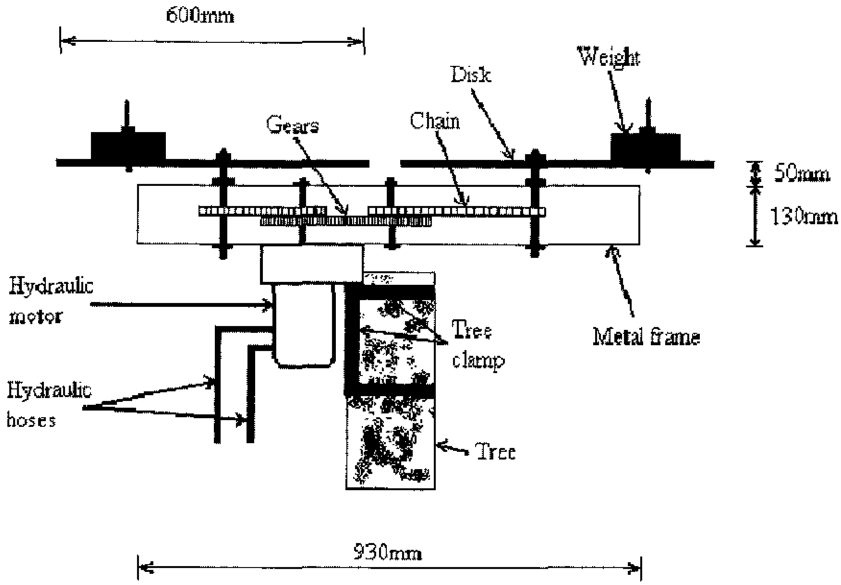

Figure 3: Elevation of tree rocker.

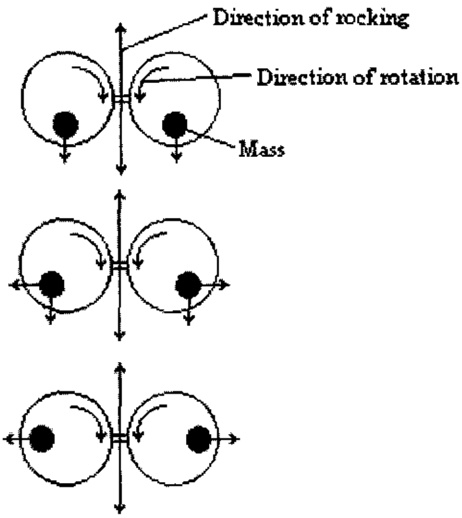

Figure 4: Plan view of rocker disks showing principle of operation (mass was varied to increase/decrease moment).

truncated stems of the test trees 6 m above ground surface. Using the rocking device, it was possible to rock the tree in a selected vertical plane.

Each of the trees subjected to dynamic testing was instrumented with eight transducers to monitor various responses of the tree and the soil beneath the tree during the forced loading experiments. Three saturated pore water pressure transducers (Figure 5) were inserted to a depth of 400 mm below the ground surface at locations close to the stem of the test tree and the major structural roots. The pressure transducers were calibrated in the laboratory using GDS pressure controllers.

Three strain gauges were mounted on the tree stem at heights of 1.3 m, 2.3 m and 3.3 m above ground surface. The strain gauges were formed by attaching a displacement transducer with a spindle displacement of 5 mm to the stem of the test tree and pressing the spindle of the transducer against a plate that had also been fixed to the test stem, as illustrated in Figure 6.

The horizontal displacement of the stem at 6 m height was measured using the arrangement illustrated in Figure 7; a similar arrangement was used for the horizontal displacement at 3 m height. As the tree rocked, the spindle of the displacement transducer was either compressed or extended in response. Knowing the dimensions of the lever arm it was possible to calculate the actual horizontal displacement of the tree stem. The transducer used to measure the horizontal displacement at the 6 m height had a spindle displacement of 100 mm and that used at the 3 m height had a spindle displacement of 50 mm; all displacement transducers were calibrated in the

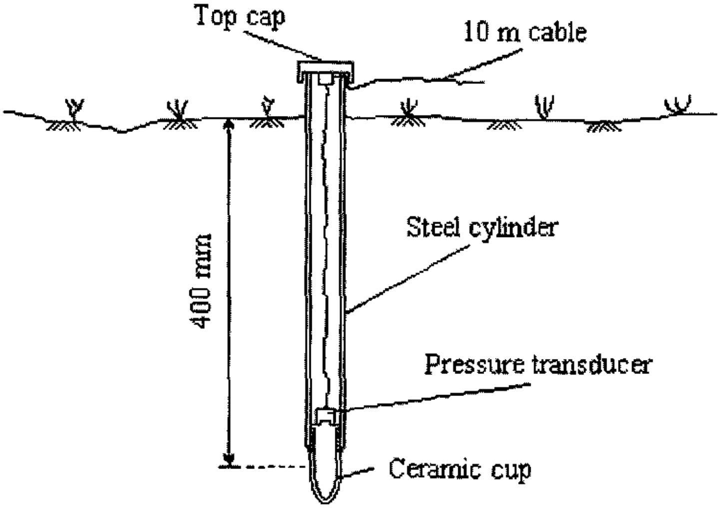

Figure 5: Pore water pressure measurement.

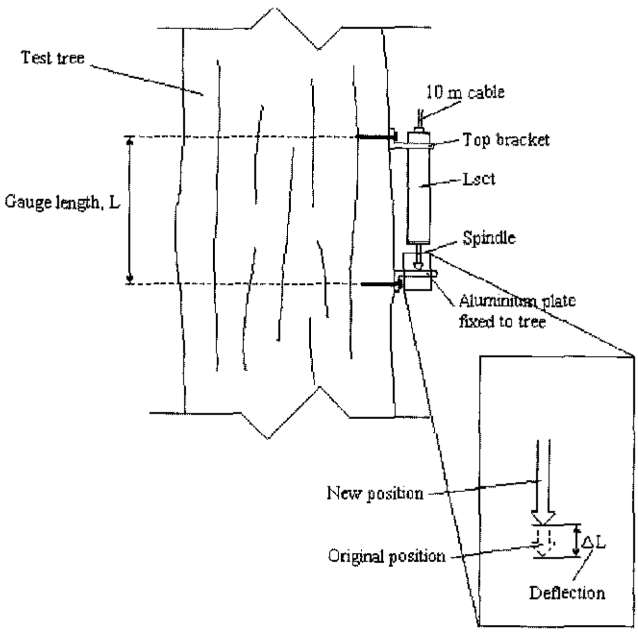

Figure 6: Stem strain gauge arrangement.

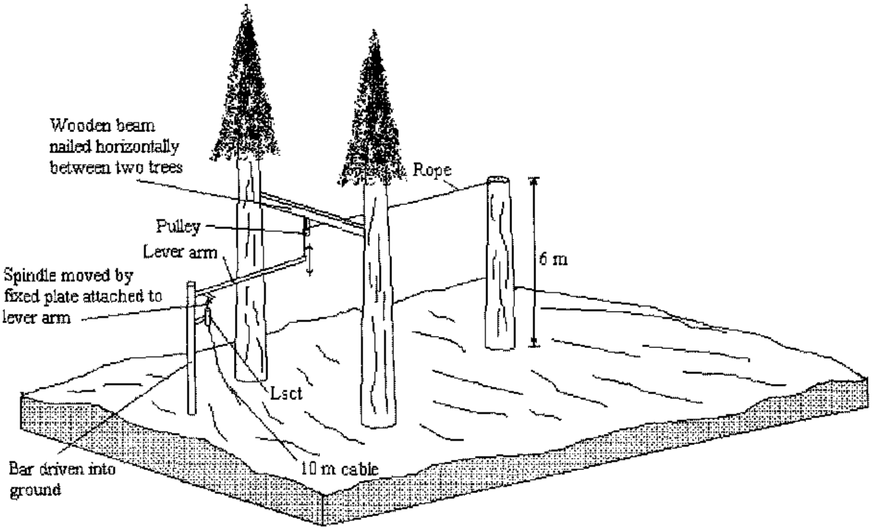

Figure 7: Horizontal stem displacement measure arrangement.

laboratory using a micrometer. The readings from the eight transducers were sampled on a Macintosh II computer using a National Instruments™ NB-MIO-16H-9 analogue-to-digital board and LabVIEW™, a software development package. This arrangement enabled results to be plotted and checked in the field when a test was in progress.

In the double mouldboard ploughed plot and mole-drained plot, the direction in which the trees were monotonically pulled or dynamically loaded was chosen at right angles to the direction of the drainage channel.

In the monotonic tests, the trees were winched over at rates varying from 0.01 to 0.02 m/s. The tensile loads in the rope were recorded every 100 mm of displacement. Pulling continued until the maximum overturning moment had been exceeded. Six trees in each of the two plots with diameters of about 220 mm at breast height (dbh) - 1.3 m above ground surface - were tested in this fashion (Table 1). Overturning moments were calculated using the following equation (Figure 8):

$$\text{Overturning moment (kNm)} = F.(\cos\theta \times L + \sin\theta \times e) \qquad [1]$$

where:

F = the tensile force in the wire rope (kN),
θ = the angle of the wire rope relative to the horizontal (°),
L = the lever arm (m), and
e = the eccentricity of the displaced stem (m).

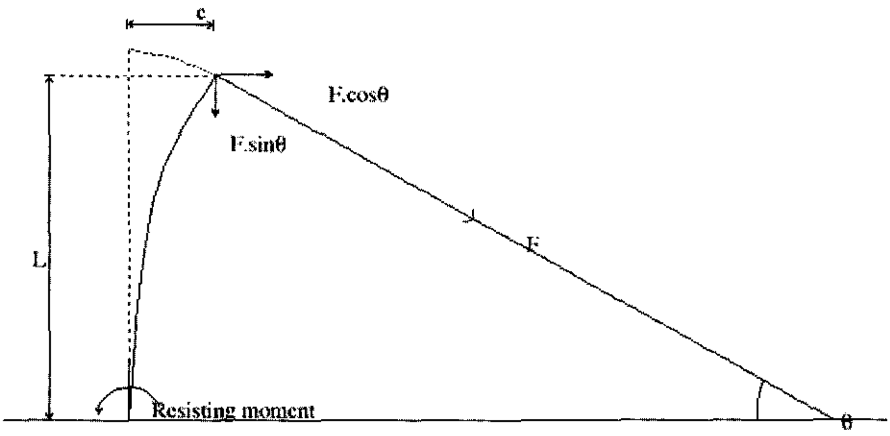

Figure 8: The components of force, overturning moment and displacement for tree pulling tests.

The repeated forced loading tests were carried out on a tree with a dbh of 220 mm in each of the experimental plots. The pore water pressure transducers were installed two days prior to testing to allow water pressures in the soil and transducers to equilibrate. A non-destructive monotonic test was conducted on the test tree before dynamic testing commenced. The tree was pulled over by a small total amount so that no damage was caused to the root plate. During the test, readings from the three strain gauges and the load cell were recorded at selected displacement intervals. The overturning moments were calculated and plotted against the strain gauge readings, yielding near linear relationships (Figure 9).

The linear relationships were used to estimate the overturning moments from the strain gauge values measured during dynamic testing. The stiffness of the test trees was calculated prior to the dynamic tests and at intervals during the test when rocking was stopped to facilitate changing the masses on the disks. The stiffness was defined using the following equation:

$$\text{Stiffness (kN/m)} = \frac{\text{Applied force}}{\text{Horizontal deflection at 6 m}} \qquad [2]$$

Rocking was initiated with small masses on the disks and a slow rotation rate. Readings from the eight transducers were monitored at selected intervals and when no further changes in their responses were observed, the rotation rate was increased. When a high rate of rotation was attained and no further changes in the responses were observed, testing was suspended for a stiffness test and to increase the masses on the disks. This procedure was followed until the test was terminated. The actual repeated loading test times for the trees in the double mouldboard ploughed and mole-drained plots were 415 and 400 minutes, respectively. The total time taken to complete each dynamic test was about 6 days. After completion of the repeated

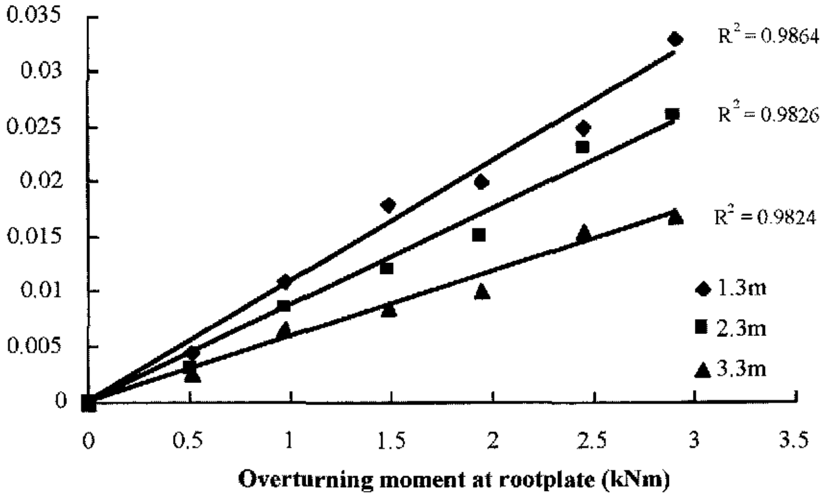

Figure 9: Calibrations to calculate overturning moment from bending strain for repeated loading test in the double mouldboard plot.

loading test, the tree was pulled over and its maximum overturning moment calculated.

Results and discussion

The results from the monotonic tests are presented in Table 1. The average value of the maximum overturning moments for the trees in the mole-drained plot was significantly ($p \leq 0.05$) greater than the average value in the double mouldboard plot.

Overturning moments obtained from the monotonic loading tests are plotted against displacement in Figure 10 for tress of the same dbh in the mole-drained and double mouldboard plots.

Table 2 shows that the dynamically loaded test tree in the mole-drained plot was 1.5-2.3 times as stiff as the test tree in the double mouldboard plot before, during and after the repeated loading tests.

For the double mouldboard test tree, there was little increase in pore water pressure (Figure 11) as the disk loading and rotation rate of the rocker were intermittently increased to 36.29 kg/disk and 42 revolutions per minute (rpm), respectively, during the initial testing time of 350 minutes. However, once the rotation rate was increased to 50 rpm at 350 minutes, the pore water pressure increased rapidly from a value of 0 kPa to a maximum value of 5.5 kPa at 370 minutes. As 1 kPa of water pressure corresponds to a 100 mm water head, water would have risen to a maximum height of 150 mm above the ground surface in a standpipe piezometer if installed at the level of the transducer tip - 400 mm below ground surface. At approximately 370 minutes, the soil fractured due to the increased pore water pressure and liquefied soil began to appear at the ground surface. At hydraulic fracture and soil liquefaction – indicated by a decrease in pore water

Table 1: Summary of destructive tree pulling tests in Sitka spruce at Ballyfarnon.

Treatment	***Tree***	***dbh*** ***cm***	***Maximum overturning moment*** ***kNm***	***Mean*** ***kNm***
Mole-drained				
	1	*22.5*	*29.23*	
	2	*22.7*	*27.21*	
	3	*22.1*	*33.14*	*32.23 ± 5.06*
	4	*22.2*	*27.97*	
	5	*22.0*	*35.66*	
	6	*22.1*	*40.16*	
Double mouldboard ploughing				
	1	*22.6*	*23.18*	
	2	*22.0*	*23.96*	
	3	*22.0*	*15.46*	*20.35 ± 3.47*
	4	*22.0*	*18.18*	
	5	*22.0*	*22.87*	
	6	*22.1*	*18.46*	

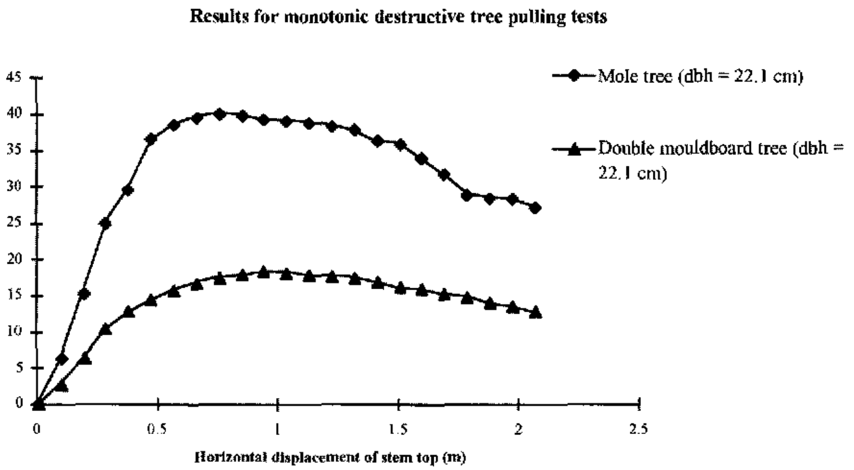

Figure 10: Overturning moments of trees in mole-drained and undrained plots as a function of horizontal stem displacement.

Table 2*: Summary of results of non-destructive swaying of Sitka spruce stems in mole drained and double mouldboard ploughed treatments at Ballyfarnon.*

Treatment	***Time*** ***min***	***Stiffness*** ***kN/m***
Mole-drained		
	0	*12.76*
	31	*12.54*
	72	*11.93*
	158	*10.46*
	401	*9.29*
Double mouldboard ploughing		
	0	*8.68*
	30	*8.65*
	190	*7.83*
	326	*5.91*
	415	*4.08*

pressure - the maximum cyclic horizontal displacement of the stem top increased to about 500 mm. The overturning moment increased from about 10 to 17 kNm during the same period even though neither the masses on the disks nor their speed of rotation were increased. This increase in overturning moment was due to the increased displacement of the rocker. When the overturning moment and displacements had reached their highest values – at about 375 minutes- the motion of the tree changed from oscillating in a single vertical plane to an erratic looping action in plan indicating that the natural frequency of the tree system had changed. The rotation rate of the tree was reduced to 29 rpm. This generated an overturning moment of about 11 kNm and a horizontal sway of 200 mm, which was about the same as that for 42 rpm phase prior to liquefaction, indicating that the tree had less stiffness once the soil fractured. The tree was then monotonically tested to failure and had a maximum overturning moment of 22.9 kNm. The dynamic data suggest that failure of the tree was initiated at an overturning moment of about 10 kNm, which is substantially lower than the maximum overturning moment obtained from the monotonic destructive test carried out on the tree after dynamic testing was complete.

Figure 12 illustrates the maximum cyclic pore water pressure behaviour and maximum cyclic overturning moments for the tree tested in the mole-drained plot. Despite a higher loading regime than used on the tree in the double mouldboard plot, only a small increase in the pore water pressure was recorded at about zero pore water pressure. The maximum overturning moment of 15 kNm was in excess of the 10 kNm value that initiated failure in the test tree in the double mouldboard plot. No hydraulic fracturing or soil liquefaction was observed. The maximum cyclic

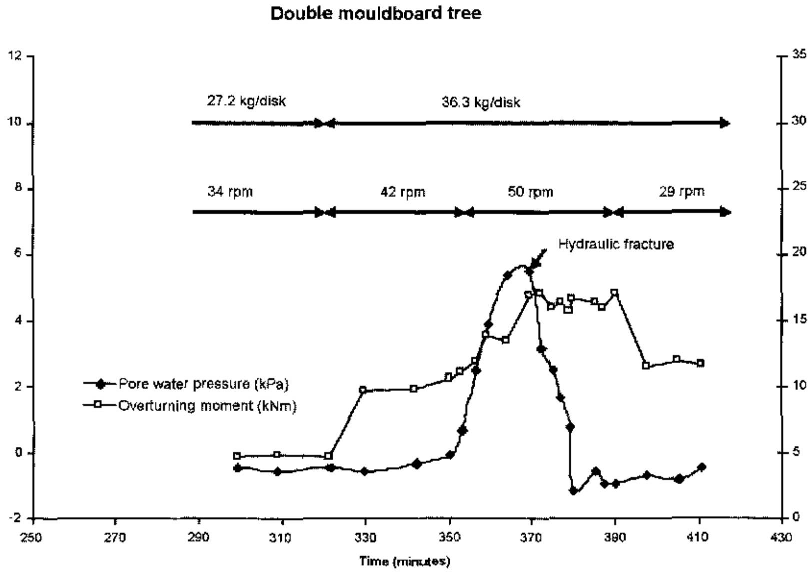

Figure 11: Pore water pressure and overturning moments for the tree tested in the double mouldboard plot.

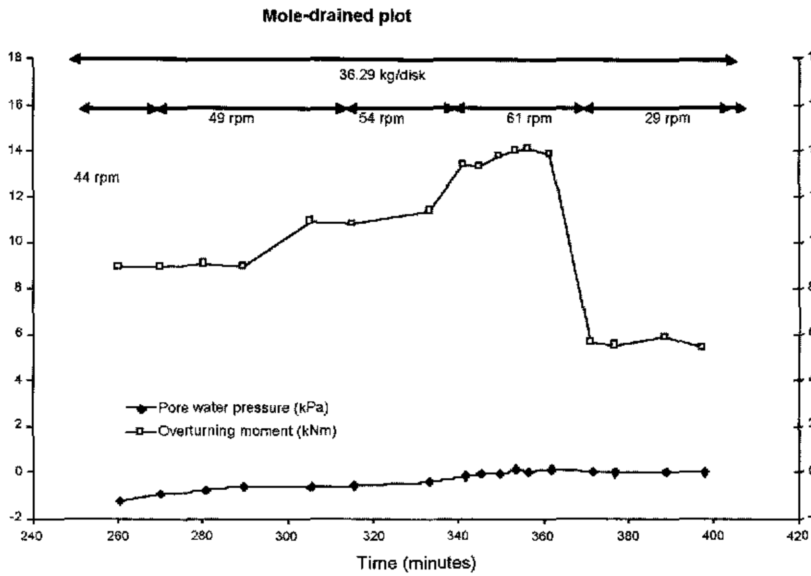

Figure 12: Pore water pressure and overturning moments for the tree tested in the mole-drained plot.

horizontal displacement of 300 mm at the stem top was also less than the maximum cyclic horizontal displacement of 500 mm of the stem top in the double mouldboard plot. Under the high loading regime a looping action in plan was induced, though it was considerably less pronounced than was the case for the tree tested in the double mouldboard plot. This looping action indicates that some fatiguing had occurred within the rooting system. This is confirmed by the measured values of stiffness in Table 2, which show a decrease throughout the course of the test. The rotation rate of the disks was then reduced to 29 rpm giving a horizontal sway of 50 mm, which was substantially less than the 200 mm for the double mouldboard tree at the same loading and rotation rate after liquefaction had occurred. Figure 12 shows that there was very little change in pore water behaviour before and after the looping took place. The tree was then pulled over with a maximum overturning moment of 33 kNm. It is worth noting that the maximum overturning moments obtained in the pulling tests for the two trees that were subjected to repeated loading are close to the average values obtained for the trees that were only monotonically loaded. This demonstrates that a monotonic pulling test gives limited information on the actual mechanism by which windthrow occurs.

Conclusions

1. The dynamic forced rocking test caused high pore water pressures, hydraulic fracture and liquefaction of the soil in the double mouldboard plot. The tree tested in the mole-drained plot, despite being subjected to a more severe loading regime, showed only a small increase in pore water pressure in the soil, smaller sway and no failure of the soil was observed.
2. Mole drainage, at a depth of 0.45 m below ground surface, should be used on surface water gley soils for planting Sitka spruce trees, where slope and field conditions allow. This drainage encourages roots to grow to the depth of the drain resulting in an increase in root plate weight and a reduction in pore-water pressure build-up in the soil in windy conditions.
3. Monotonic pulling tests, which are widely used, do not simulate the conditions experienced by trees during windy conditions. The repeated forced loading tests clearly show that soil failure can be initiated at much lower overturning moments than the maximum overturning moment applied during monotonic pulling tests.
4. The study shows that the stability of slender structures founded on slow draining soils can be substantially improved by proper soil drainage.

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Growth models for Sitka spruce in Ireland

Lance. R. Broad[a] and Ted Lynch[b]

Abstract

Ad hoc techniques were used to fit stand-level growth models for Sitka spruce in Ireland in the presence of sampling biases. Panel data, sourced by aggregation over a set of repeated measures experimental designs, admitted sampling biases when considered as a data set for yield modelling purposes. Remedial action towards sampling imbalances was taken, whenever possible, through the use of weighting techniques. Further action to address data omissions involved using data substitution. The growth component model used was the multivariate Bertalanffy-Richards model formulated by García. The model allows aggregated state-space representations of stand development to be formulated and fitted. For stand simulations, growth equations were augmented with functions accepting state variables as arguments and compute basal area reduction during any thinning, stand volume and volume assortments.

Keywords: Assortments, growth models, multivariate growth, Sitka spruce, weighting techniques.

Introduction

Sitka spruce (*Picea sitchensis* (Bong.) Carr.) was first introduced into Ireland from British Columbia in the 1830s. Publicly funded afforestation followed in 1904 (Joyce and OCarroll 2002). The species has flourished within its Irish setting and a prosperous forest industry based on its utilisation has developed. Since the 1960s, this industry has relied heavily upon Forestry Commission (FC) yield tables and the stand management concepts surrounding them (Johnston and Bradley 1963).

However, there are aspects of modern forest management that the FC yield tables are less equipped to deal with Specifically, the FC tabular models are not well suited to introducing ideas from economics regarding the management of natural resources and optimal stand or forest management. Consequently, the aim of this work was to develop an alternative growth projection mechanism for Sitka spruce that is amenable to simulating a wide range of management alternatives specific to Irish conditions. Two Sitka spruce models were developed – a model for un-thinned stands and a model for thinned stands.

Reliably constructed growth models that permit growth and yield forecasting are crucially important for management of forest plantations. Silvicultural and economic planning at the stand and forest estate level are contingent on being able to forecast growth accurately at the stand level. Until the pioneering work of Clutter (1963) the problem of determining annual increments within forest stands, i.e. growth assessment, was conducted separately from that of determining stand aggregates or yield assessment. Clutter showed that the increments could be derived from the

[a] Technical Forestry Services, New Zealand.

[b] Coillte Research and Development, Newtownmountkennedy, Co Wicklow, Ireland (corresponding author, ted.lynch@coilte.ie).

associated yield curves and vice-versa by the mathematical operations of differentiation and integration.

A plethora of methods have been developed to represent forest growth in even-aged stands. These can be classified using a relatively small number of criteria that convey the essential differences. *Static* models assume that stands are managed to some prescribed pattern over the rotation. Within a European context the FC Management tables (Forestry Commission, 1981) is the best-known example. *Dynamic* models, on the other hand, do not assume prescribed management regimes and therefore can be used to forecast the outcome of a wider range of thinning practices. These models rely on modelling incremental changes in the variables of interest over time. The corresponding yield is then obtained by integrating or summing the incremental changes.

García (1979) gave a fillip to dynamic models through the development of systems of differential equations to model forest yield. The multivariate extension of the Bertalanffy-Richards model developed by García permit simultaneous estimation of growth component equations can take place. García introduced further ideas from systems theory into a forestry context, to describe how a forest stand evolves over time. This requires:

1. an adequate representation of the system (stand variables) at any point in time - the so called *state* of the system, and
2. estimates of the rate of change of state, and of the current value of any external control variables.

Using such a framework the central elements of differing yield prediction systems can be compared. To illustrate, models based on individual tree position maintain a more detailed state description compared with those that operate at the stand-level. From a practical forest management viewpoint, a growth model must provide the requisite forecasts without too much in the way of operating overheads. This requirement has led to growth models that are used for management purposes being developed at the aggregation level of a forest stand. Forest level prediction is then made through aggregating stand level predictions.

This work sets out by describing a class of functions that jointly constitute a García yield model. This class is augmented with a function for generating assortments. The fitting of these functions in the presence of sampling biases is subsequently described. General aspects relating to the deployment of the resulting dynamic yield model are discussed.

Methods

The development of stand-level growth models for Sitka spruce proceeded by adopting the state-space modelling methodology advocated by García (1984). That is, a small number of stand variables were chosen to represent the stand. Future states of the stand can then be determined from the current state, provided any future actions such as thinnings are detailed. The variables included in the state allow the subsequent calculation of quantities of interest such as stand volumes, log assortments and thinning reductions. Thus, a stand volume equation is employed to estimate stand volumes; an assortment generator predicts proportions of stand volume found in various log categories; and a thinning equation calculates basal area or stocking reductions during any possible thinning. A formal description of each component sub-model is now given.

Growth equations

The growth projection mechanism employed consisted of a system of differential equations formulated by García (1979). The system is sufficiently flexible to permit both empirical growth modelling, where no assumptions are made as to relations between stand variables, and modelling in limited data situations where known biological principles are used as a basis for forming equations (García and Ruiz 2003).

In formulating this system, García proceeded by way of generalising equation (1), the basic univariate Bertalanaffy-Richards model expressed as a linear differential equation in x^C. Here variable x is some measure of size such as top height and parameters are a, b and c.

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

The power transform (2) is required to generalise the scalar exponential term x^C present in equation (1) to multivariate situations. The left hand side of (2) employs a non-standard mathematical notation, a vector being raised to a matrix power. This is computed using the expressions on the right hand side of the identity (assuming the logarithm and exponential functions are extended to a vector argument on an element-by-element basis).

$$\mathbf{x}^{\mathbf{C}} \equiv \exp(\mathbf{C}\ln\mathbf{x}) \tag{2}$$

Here $\mathbf{x}$ is an arbitrary n dimensional vector and $\mathbf{C}$ is an arbitrary n x n matrix. To illustrate, if the state vector used to represent the stand is chosen to be basal area (B) (m^2 ha^{-1}), stocking (N) (stems ha^{-1}), and top height (H) (m), then take $\mathbf{x} = (B, N, H)^T$ and $\mathbf{C}$ as a 3 x 3 matrix of *reals* with elements c_{ij}, then by extending the exponential and logarithm functions as indicated above the resultant 3 x 1 vector can be expressed as

$$\mathbf{x}^{\mathbf{C}} = \begin{bmatrix} B^{c_{11}} N^{c_{12}} H^{c_{13}} \\ B^{c_{21}} N^{c_{22}} H^{c_{23}} \\ B^{c_{31}} N^{c_{32}} H^{c_{33}} \end{bmatrix}$$

The above illustrates that raising the state vector to a matrix power is a form of coupling transformation, since a new vector has been formed whose elements are multiplicative combinations of the original vector elements raised to appropriate powers.

The analogous multivariate system is specified as

$$\frac{d\mathbf{x}^{\mathbf{C}}}{dt}=\mathbf{A}\mathbf{x}^{\mathbf{C}}+\mathbf{b} \tag{3}$$

The above approach proceeds from the univariate to the multivariate model by way of exploiting the power transform given in equation (2). Within the differential equation system (3), a single equation is devoted to predicting top height growth. This equation also governs how the effects of site are incorporated into all of the system equations in (3). The top height development equation has equation form (1) which, assuming $H(t)$ denotes top height in metres at age t, may be expressed as

$$\frac{d\,H^C}{d\,t} = b(a^C - H^C) \tag{4}$$

Whose solution is

$$H(t) = a\left(1 - \left(1 - (H_0 / a)^c\right)\exp(-b(t - t_0))\right)^{1/c}$$

When parameter b is used as the site indexing parameter then the site index curves that arise are termed *polymorphic* and curves differ by what amounts to a *time scaling*. Parameter a is then interpretable as the asymptotic top height while parameter c can be regarded as a linearisation parameter, since equation (4) is a linear differential equation in the variable H^C. Equation (4) has been integrated subject to the initial condition $H(t_0)=H_0$.

From the solution of equation (4), b may be expressed in terms of the site index S (top height at age 30) and the stand top height initial condition

$$b=-\frac{1}{30-t_0}\ln\left[\frac{a^c-S^c}{a^c-H_0^c}\right] \tag{5}$$

Should a or c be chosen as the site indexing parameter then *anamorphic* site index curves would arise. Under a polymorphic site index curve the effect of site within the system (3) can be accommodated through scaled time. This means **A** and **b** change by a multiplicative factor to express site differences, while **C** is independent of site. Consequently, in system (3) there is no relationship between site and the state variables (García 1984).

Assuming the state vector has elements $\mathbf{x} = (B, N, H)^T$ then the following form of system (3) was employed to represent growth on an empirical basis for thinned and un-thinned stands. The derivatives are now taken with respect to $\tau = bt$, the scaled time variable.

$$\frac{dB^{C_{11}}N^{C_{12}}H^{C_{13}}}{d\tau}=a_{11}B^{C_{11}}N^{C_{12}}H^{C_{13}}+a_{12}B^{C_{21}}N^{C_{22}}H^{C_{23}}+a_{13}H^{C_{33}}+b_1$$
$$\frac{dB^{C_{21}}N^{C_{22}}H^{C_{23}}}{d\tau}=a_{21}B^{C_{11}}N^{C_{12}}H^{C_{13}}+a_{22}B^{C_{21}}N^{C_{22}}H^{C_{23}}+a_{23}H^{C_{33}}+b_2 \quad (6)$$
$$\frac{dH^{C_{33}}}{d\tau}=-H^{C_{33}}+b_3$$

In terms of matrices **A** and **C** now have dimension 3 x 3, **b** is a 3 x 1 vector. García (1984) deployed a useful version of this model that arises from setting $a_{22} = a_{23} = b_2 = c_{21} = c_{23} = 0$. Then fitted values of c_{22} and a_{21} having opposite signs mean that stocking levels will decrease over time. Setting a number of parameters to zero also diminishes the number of parameters to be found. This simplified model was used as a base model prior to the fitting of system (6).

García (1984, 1989) also considered extensions to system (6) so as to examine responses to fertiliser treatments and thinning effects. Both can be examined using multiplier functions which are effectively time scaling devices. Thinning effects can also be modelled through augmenting the state vector through the use of an additional state variable R representing *relative closure* or site occupancy after thinning. Relative closure has values between 0 and 1. Assuming full closure is represented by a value of 1, its value after a thinning is reduced to the basal area of the thinned stand as a proportion of the basal area prior to thinning. After thinning, closure is assumed to increase towards its asymptotic value of 1. Relative closure is an unobservable variable in that its value is not directly available at all times through measurement, however, it is still amenable to inclusion within a state vector since the means by which its value changes are known.

System (6) is linear in the transformed state vector $\mathbf{x}^C$ and consequently can be integrated analytically between times that do not involve thinning. Given the initial state $\mathbf{x}_1$ at time t_1, García (1984) indicates the expected solution at time t_2 as

$$\mathbf{x}(t_2) = \left\{\mathbf{a} + \mathbf{P}^{-1}e^{\Lambda b(t_2-t_1)}\mathbf{P}\left[\mathbf{x}(t_1)^{\mathbf{C}} - \mathbf{a}\right]\right\}^{\mathbf{C}^{-1}} \quad (7)$$

Where Λ (diagonal matrix of eigenvalues) and **P** (matrix of left eigenvectors) form the eigenvalue-eigenvector decomposition of the matrix $\mathbf{A} = \mathbf{P}^{-1}\Lambda\mathbf{P}$, and $\mathbf{a} = \mathbf{A}^{-1}\mathbf{b}$ is the asymptote vector for system (3). Note the presence of the time scaling parameter b within the exponential term - this represents the effect of site adjusting time.

Volume equation

A common stand level volume equation that predicts the volume basal area ratio as a function of top height is

$$V / B \cong a + bH \quad (8)$$

Where a and b are parameters to be determined. The ratio V/B is used in that it tends to induce homogeneity in the error variance.

Beekhuis (1966) observed that equation (8) cannot be valid both before and after a thinning. Thinning *from below* tends to remove trees of smaller height so the volume to basal area ratio must increase after a thinning event. García (1984) suggested a modification whereby further terms involving N or B are admitted as predictors. Site index, S, may also be used to account for site effects (García, pers. comm.). A stand-level volume equation is then generally determined as

$$\frac{V}{B} \cong \beta_0 + \sum_{i=1}^{n} \beta_i \, g_i\left(B, N, H, S\right) \qquad (9)$$

The right hand side of equation (9) denotes that the volume to basal area ratio is expressed as a linear function of terms involving basal area, stocking, top height and site index. Each g_i function is a multiplicative expression of its arguments that are possibly raised to powers. Explicitly, equation (9) is expressed in terms of a predictor set such as H, $H/\sqrt{N}$, NH/B, $1/H$, H/N, B/H, S/B, S/B^2 and the model identified by stepwise linear regression techniques.

Thinning equation

The thinning equation proposed by García (1984) allows for the determination of post-thinning basal area (*resp.* stocking) when the top height, pre-thin basal area, pre-thin stocking and post-thin stocking (*resp.* basal area) are known. When expressed as a differential equation it has the form

$$\frac{d \ln B}{d \ln N} = a B^b N^c H^d \qquad (10)$$

The left hand side of (10) is interpretable as the percentage change in basal area arising from a percentage change in stocking. This interpretation follows from the expression $d \ln B / d \ln N = (dB/B)/(dN/N)$. Consequently, equation (10) is a model of the stocking elasticity of basal area (Silberberg 1990).

The equation is separable and on integration its solution is obtained as

$$\ln B = -\frac{1}{b} \ln\left[B_0^{-b} - \frac{ab}{c} H^d \left(N^c - N_0^c\right)\right]$$

Where H denotes the top height, B_0 and N_0 are the pre-thin basal area and stocking and the post-thin values are B and N. The model parameters to be determined by nonlinear least squares are a, b, c, and d.

A useful property of differential equation models is that they are closed under the operation of *composition*. With respect to the thinning equation this means a thinning removing 200 stems ha^{-1} followed immediately by another thinning removing 300 stems ha_{-1} results in the same basal area reduction as a thinning of 500 stems ha_{-1}. This consistency property will always arise when differential equations are used as transition functions. System (3) gives rise to a similar consistency condition when projecting over time (García 1994).

Using the thinning equation (11) in conjunction with the stand volume equation (9) allows for thinnings to be performed by volume reduction. The thinning equation permits the stand volume after thinning to be expressed as $V(B, N(B; B_0, N_0), H)$, where post-thin stocking is given as a function of post-thin basal area (pre-thin basal area and stocking appear as parameters within the thinning equation). This means Newton's algorithm (Conte and de Boor 1972), or some similar technique for locating function roots, can be deployed to reduce the basal area from its pre-thin level, to post-thin level, to simulate the extraction of a specified volume of thinnings. Similarly, it is possible to simulate the effect of thinnings by increasing quadratic mean diameter. The procedure would be to employ a root finding technique to reduce B and at each step, use the thinning equation to predict $N(B; B_0, N_0)$ and consequently recover the quadratic mean diameter (terminate the step-wise procedure with success if the quadratic mean diameter has reached its target value).

Assortment equation

An assortment model is used to calculate assortments for any production thinnings and the crop. Generally, the problem of estimating assortments is that of delineating a set of categories (log classes), and determining the proportion associated with each category (assortment), such that the proportions sum to unity. Past endeavours to solve this problem have focused on sectioning a diameter distribution (García 1981) and subsequently employing a taper function to calculate the quantities of interest. More recently, the problem has been addressed using techniques that model the proportions directly, such as multinomial response models (Arabatzis and Gregoire 1990). These are a class of what are known as limited dependent variable regression models.

The model defined as Unordered MultiNomial Logistic (UNML) by Arabatzis and Gregoire (1990) was employed here largely because of its flexibility in permitting differing numbers of predictors to be associated with each *category*, and because it does not require any common slopes assumption as does the Ordered MultiNomial Logistic (OMNL) model. Assuming a variable Y is used to indicate the J+1 categories, indexed 0 through J, then the UNML model is expressed as

$$\Pr[Y_i = j] = \frac{\exp(\hat{\mathbf{a}}'_j \mathbf{x}_{ij})}{1 + \sum_{k=1}^{J} \exp(\hat{\mathbf{a}}'_k \mathbf{x}_{ik})}$$
$$\Pr[Y_i = 0] = \frac{1}{1 + \sum_{k=1}^{J} \exp(\hat{\mathbf{a}}'_k \mathbf{x}_{ik})} \qquad (12)$$

Here i denotes an observation subscript and j a category subscript. While $\mathbf{x}_{ik}$ denotes predictors associated with category k and observation i. Finally β_k denotes parameters for category k. The probability of category 0 is determined by subtraction.

The equations given in (12) can be adapted to obtain assortment predictions for crops with, or without, thinning. The approach involves partitioning the predictors associated with each category (the observation subscript has been dropped for convenience).

$$\mathbf{x}_j^T = \mathbf{x}_{j1}^T \mid \mathbf{x}_{j2}^T \tag{13}$$

Where

$\mathbf{x}_{j1}$ is the set of predictors for category *j* associated with the main crop; and
$\mathbf{x}_{j2}$ is the set of predictors for category *j* associated with the thinning.

The underlying idea is that an assortment for a thinning is obtained by way of a modification to the pre-thin crop assortment. The extent of the modification to the crop assortment depends on the severity of the thinning. The predictor variables in the vector $\mathbf{x}_{j2}$ form part of the prediction only if a thinning assortment is being predicted (they are defined to be zero otherwise). Generally, variables in $\mathbf{x}_{j2}$ have special structure that provides a measure as to the extent of thinning. This is achieved by ensuring they are functions of $N_0 - N_1$, $B_0 - B_1$, $D_1 - D_0$. Here N_0 and N_1 are the stocking per hectare before and after thinning, B_0 and B_1 the respective basal areas, and D_0 and D_1 respective quadratic mean diameters (expressed in centimetres). Ratio terms can also be utilised.

Predictions are made for two log categories. Category one is an estimate of the proportionate volume of logs of at least 3 m length, and having small end diameter (SED) equal to or greater than 20 cm. Category two estimates the proportionate volume of logs having small end diameter in the interval 14 to 20 cm. Category 3, is obtained by difference from unity, and estimates the proportionate volume in the 7-14 cm SED category.

The standard multinomial model has been modified in two respects. Firstly, categories are permitted to have a different numbers of predictors associated with them. Secondly, a weighted form of the likelihood used in parameter estimation has been formulated to cope with data imbalances (see Appendix 1). Using a different number of predictors for each category means good model identification can take place via a log odds ratio and stepwise linear regression techniques.

Data provenance

The bulk of the data used in fitting models were extracted from Coillte Teoranta's (the Irish Forestry Board – the state commercial forestry company) permanent sample plot record system. The associated database contains records from many silvicultural and thinning trials established during the period 1963 to 2001. The trials were initially established as replicated experimental designs with repeated measurement. Issues relating to the use of *blocked data* within a yield modelling context are discussed by Broad and Lynch (2006).

Aggregating data across repeatedly measured designed experiments, each of which is a well-designed experiment, does not guarantee a well-structured data set for the purposes of yield modelling. Coillte has no experiments established in unthinned stands having site indices below 10.5 m, yet some 21.1% of its un-thinned estate has site indices below this level. Similarly, for thinned stands with site indices below 13.5 m, approximately 1.2% of its experimental data falls in this range compared with 21.16% for the estate data (see Figure 1, Broad and Lynch (2006)).

These data omissions would be best rectified through an additional sampling scheme specifically designed to address the imbalance. The approach taken here was to use data substitution to facilitate growth model development in the absence of further sampling. Substituted data occurred below site index 15.0 (m) were sourced from Booklet 48, Forestry Commission (1981).

Parameter estimation

The above equations were fitted to data extracted from the Coillte permanent sample plot database. Obtaining data records in a form suitable for model fitting was facilitated by a database query program written using Microsoft Access®. The program forms a useful tool for validating data from permanent sample plot records and subsequently extracting data for growth modelling purposes. The validation code performs both basal area, and sample tree volume checks. The data extraction code takes the validated records and prepares aggregate information for growth modelling purposes.

Weighting techniques were used to address some of the data imbalances within Coillte's research database (Broad and Lynch 2006). The data imbalances include unrepresentative sampling in some site index classes. The procedure for determining weights to be used in estimation procedures relies on knowledge of some attribute variable for both the sampled population and the target population. The attribute variable chosen in this study was site index. Once site index histograms are available for the sampled and target populations, sampled observations can be weighted as follows.

$$P_T \equiv \left(\frac{P_T}{P_S} \right) P_S \tag{14}$$

Where P_s denotes the proportion of sampled observations in a specified site index class and P_T is the portion of target observations in the same site index class. The sampled observations are weighted by the quotient ratio in parentheses to ensure a weighting consistent with the target population. This weighting scheme is applicable only when observations exist in the sampled site index class (they must then exist in the target class). If the target class has observations but the sampled class does not then it is necessary to aggregate over classes to ensure sampled observations exist within the aggregated sample class.

When determining the weights for a specific equation the histograms for the target and sampled populations are initially constructed. For the target population the histograms always used in weight determination are those indicated as *Estate Un-thinned* and *Estate Thinned* in Figure 1 of Broad and Lynch (2006). For the sampled population the histograms are constructed from the data used in equation fitting and consequently vary between equations. The sampled population histograms are constructed after any additions for data omissions have taken place. This process may not uniquely define a set of weights, as often more than one possibility exists for drawing the sampled population histogram. To illustrate, when fitting growth component models the sampled population histograms are constructed from the trajectory data used in model fitting. Different histograms usually arise depending on whether we use the plot site index or trajectory site index as the observation when constructing the histogram. Only when all plots have the same number of trajectories are the histograms the same.

Height growth estimation

García (1983) assumed in estimating the parameters of the height equation (4) that its increments were perturbed by a *stationary Gaussian process* with independent increments (see also Seber and Wild 1989). This permits construction of the log likelihood function and determination of the height equation parameters through log likelihood maximisation.

Site index curves are typically obtained by varying one parameter from plot to plot, although strictly speaking any function of the parameters can be chosen to vary in this manner (García 1983). Parameter(s) chosen to represent site are referred to as local parameters within the likelihood function, while those that are constant across all sites are termed global. Both anamorphic (a local) and polymorphic (b local) height equations were fitted to a height data set extracted from Coillte's database augmented with FC height trajectory data to cover data omission in lower site index classes (Broad and Lynch 2006). The final data comprised 423 trajectories of which 160 were from FC data. Weighting changes for the log likelihood were achieved by replicating observations. The FC data was afforded a higher weighting over repeated fitting attempts to lower predictions for lower site index classes.

The log likelihood function for the polymorphic model had a value of 3887.412. This was an improvement over the anamorphic model which was not considered further. The use of the polymorphic model means the suggested time scaling in system (6) can be implemented.

In the solution of the height equation the initial height H_0 (m) at time t_0 (years) is assumed to be zero. The following parameter estimates were obtained using García's height estimation program

$a = 49.348040$
$c = 0.624157$
$t_0 = -0.75$

The t_0 parameter was pinned although various candidate values were considered.

The height equation can be used to predict top heights for trees in production environments. There are non-production areas in Ireland where this equation would be conservative. Figure 1 shows a family of site index curves.

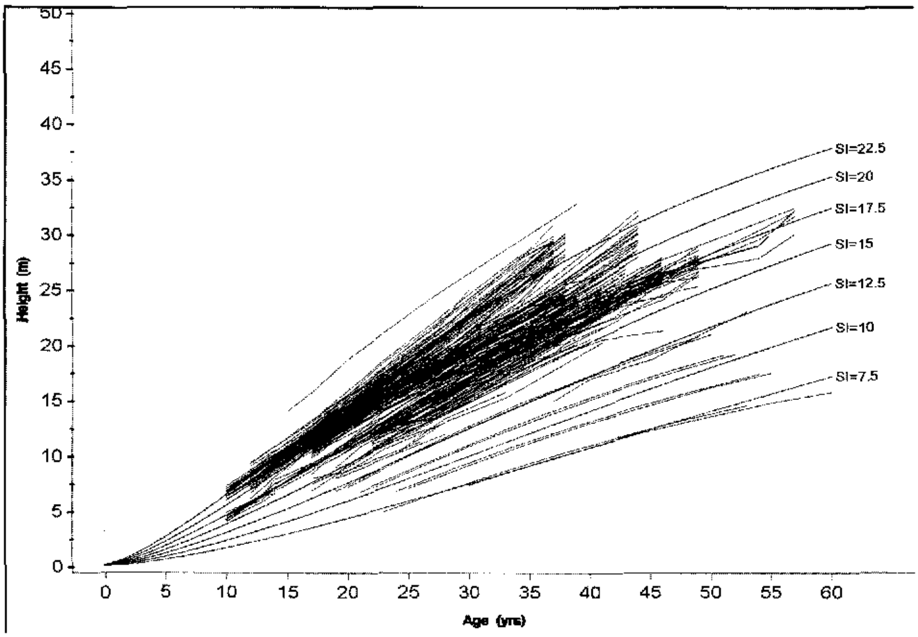

Figure 1: Sitka spruce site index curves (reference age 30 yrs).

Basal area and mortality growth estimation

Consecutive stand measurements of basal area, stocking and top height (state vector elements) in the absence of thinning form the basis of the data set used to fit the dynamical system specified in equations (3). In a thinned stand, a *growth trajectory* comprises the stand state measurement immediately after thinning (post-thin) along with that immediately prior to the subsequent thinning (pre-thin). In un-thinned stands a trajectory will arise from each consecutive pair of stand measurements. In thinned stands, windthrown trees that occur immediately prior to thinning were modelled as part of the thinning. This allows for limited recoverability of windthrown material.

The thinned model has been fitted to trajectories from stands having had *selection*, *systematic*, or *line plus selection* thinning treatments. A limited number of the trajectories from wider spaced stands were used. In addition, trajectories from un-thinned stands were incorporated in the thinned data set. This reflects the fact that all stands start out as un-thinned stands and that a wide diversity of thinning practice can exist. Additional FC data were added to address the issue of data being absent from lower site index classes (see Broad and Lynch 2006) Careful scrutiny was given to screening plot data. Basal area and mortality increments were examined along with a graphical analysis of trajectory data. In cases of obvious abnormalities, these data were no included.

For parameter estimation purposes, García (1984) assumed that the system of differential equations (3) is perturbed by a 3-dimensional Wiener-process. The resulting system of stochastic differential equations facilitates the construction of the conditional probability of observing the stand state at time t_2 given the state at time t_1. The assumption of statistical independence between plots enables the construction of the log likelihood function that provides a probability model of generating the observed data. The log likelihood function may be estimated under either a diagonal correlation structure (Method I) or full correlation structure (Method II). Method I was used throughout, as previous applications indicate that it is the most suitable for estimation purposes. The model parameters were obtained by maximisation of this log likelihood function. The full derivation of the log likelihood function is given in García (1979) and a modification to allow for zero eigenvalues is stated in García (1984). The case of zero eigenvalues is consistent with an over-specified state vector for growth modelling. However, such a vector may be useful in that its components may be used as arguments within ancillary functions such as the volume or thinning equations.

In response to the data imbalance issues identified in the research data (Broad and Lynch 2006) the weighted form of the Method I log likelihood function was developed. This was coded using Compaq FORTRAN (Compaq Computer Corporation, 2001). In all fitted models, weights were initially determined using equation (14). For each fitted model the sampled population histogram was constructed using the site indices associated with the trajectory data. Thereafter weights were modified to ensure *ad hoc* criteria were satisfied. These criteria were designed to ensure that relativities between thinned and un-thinned stands being realistic, projections across the range of site indices remaining reasonable and comparisons with FC projections remained satisfactory.

Table 1 indicates the structure of some models fitted subsequent to fitting the top height equation. For thinned and un-thinned stands the base model with parameters a_{11}, a_{12}, a_{13}, a_{21}, c_{11}, c_{12}, c_{13}, c_{21}, b_1 was initially fitted - these are models 1(T) and 4(U) in Table 1. Subsequently, the fully parameterised versions of system (6) were fitted - these are models 2(T) and 5(U) in Table 1. When examining projections from these

***Table 1**: Model fitting results (model number & thinning status (T= thinned, U=un-thinned), and parameter list (excluding top height parameters)).*

Model	*Log likelihood*	*Number of trajectories*	*Model description*
1(T)	*7926.91*	*1460*	$a_{11}, a_{12}, a_{13}, a_{21}, c_{11}, c_{12}, c_{13}, c_{21}, b_1$
2(T)	*8017.02*	*1460*	$a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}, c_{11}, c_{12}, c_{13}, c_{21}, c_{22}, c_{23}, b_1, b_2$
3(T)	*8028.80*	*1460*	$a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}, c_{11}, c_{12}, c_{13}, c_{21}, c_{22}, c_{23}, b_1, b_2, \gamma_1, \gamma_2$
4(U)	*12560.6*	*1265*	$a_{11}, a_{12}, a_{13}, a_{21}, c_{11}, c_{12}, c_{13}, c_{21}, b_1$
5(U)	*12763.4*	*1265*	$a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}, c_{11}, c_{12}, c_{13}, c_{21}, c_{22}, c_{23}, b_1, b_2$
6(U)	*12888.8*	*1265*	$a_{11}, a_{12}, a_{13}, a_{21}, a_{22}, a_{23}, c_{11}, c_{12}, c_{13}, c_{21}, c_{22}, c_{23}, b_1, b_2, \gamma_1, \gamma_2$

models it was noted that for lower site indices the fitted models tended to over-estimate when comparisons were made against FC tables. This led to an investigation of the site scaling method in system (6).

The method deployed to investigate site scaling was to use the multiplier function approach of García (1989) adapted to the scaling of the polymorphic height parameter b, rather than *relative closure* as occurs in García's application. The method was based on using a function $g(b)$ to site-scale the first two equations in system (6) rather than b. The requirements of such a function are that it be defined on some domain where $g(b)$ is less than b, thereafter it has value b. Several candidate functions were tried, the most successful of which was

$$g(b) = \begin{cases} b\left(1 + \gamma_1 (b - \gamma_2)^2\right) & \text{if } b < \gamma_2 \\ b & \text{otherwise} \end{cases} \tag{15}$$

Equation (15) is a spline comprising a modified cubic followed by a linear portion. The parameter γ_2 denotes the join point at which $g(b)=b$ and $g'(\gamma_2)=1$, the additional condition is $g(0)=0$. Nonlinear site scaling is attained for values of b below γ_2. When fitted, the parameter values obtained allow a zero for $g(b)$ at a small positive value of b. These values correspond to site indices that are outside the range of the fitted model and should pose no threat to projections.

Augmenting the fully parameterised system (6) with equation (15) led to models 3(T) and 6(U) in Table 1. All the thinned models in Table 1 have the same observation weight set. Similarly, all un-thinned models have a common, but different, weight set. From the increases in the log likelihood function at optimality in Table 1, it is apparent that the nonlinear site scaling has a beneficial effect for both thinned and un-thinned stands. Parameters for the fully parameterised models with augmented site scaling can be found in Box 1 & Box 2 of Appendix 2.

Explanation of the need of nonlinear site scaling could include: genuine nonlinear site effects at lower site indices with respect to basal area and stocking development; the data interface between Forestry Commission and Irish research data requiring nonlinear site scaling to rectify site response imbalances; an ill-fitting height equation. Discriminating between these possibilities is difficult but it is suspected that non-linear site scaling to rectify site response imbalances is responsible. The value for γ_2 corresponds to site index 14.35 (m) for thinned stands and 17.34 (m) for un-thinned stands.

Plots of observed (also used in model fitting) *v* predicted trajectories are illustrated in Figures 2-6.

Figure 2 also serves to illustrate the range of data used in the fitting of the thinned model, and gives an indication of the regions of the state space within which model projections can be made. The dense cloud of observations less than age 45 represents the bulk of the research data.

Figure 3 illustrates stocking development in thinned stands, with the bulk of the data with stocking levels of 3500 stems ha^{-1} and less.

Height development is indicated in Figure 4. Both thinned and un-thinned models share a common height equation.

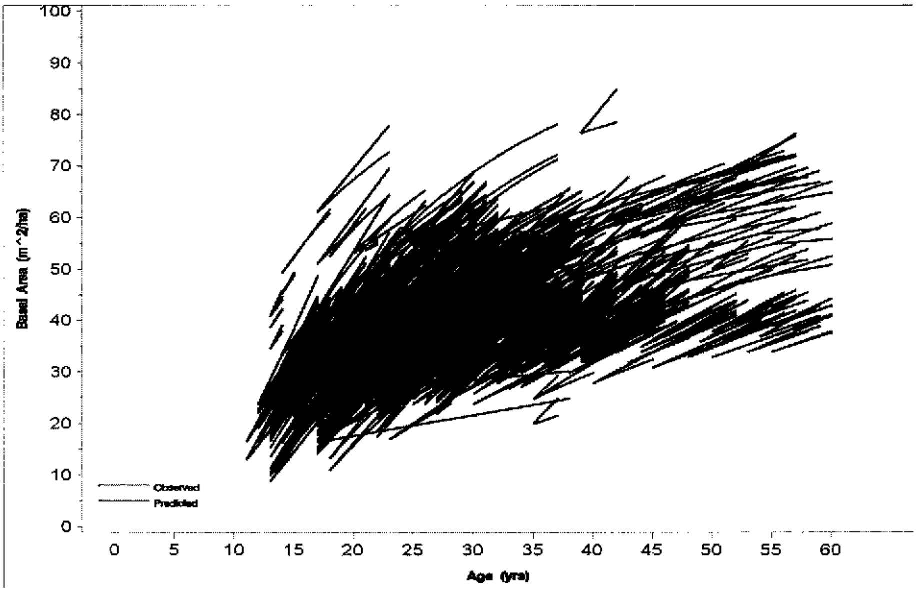

Figure 2: Sitka spruce (thinned) observed v predicted basal area development.

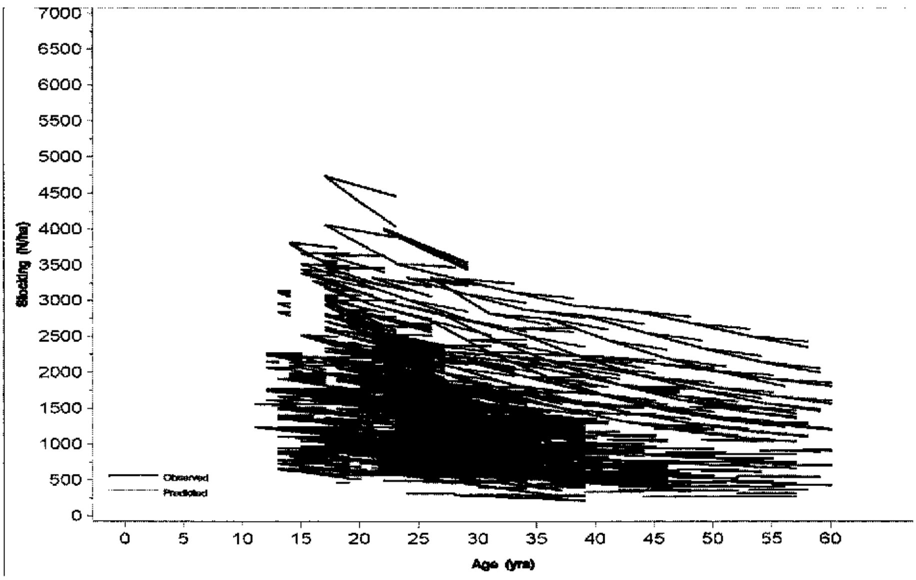

Figure 3: Sitka spruce (thinned) observed v predicted stocking development.

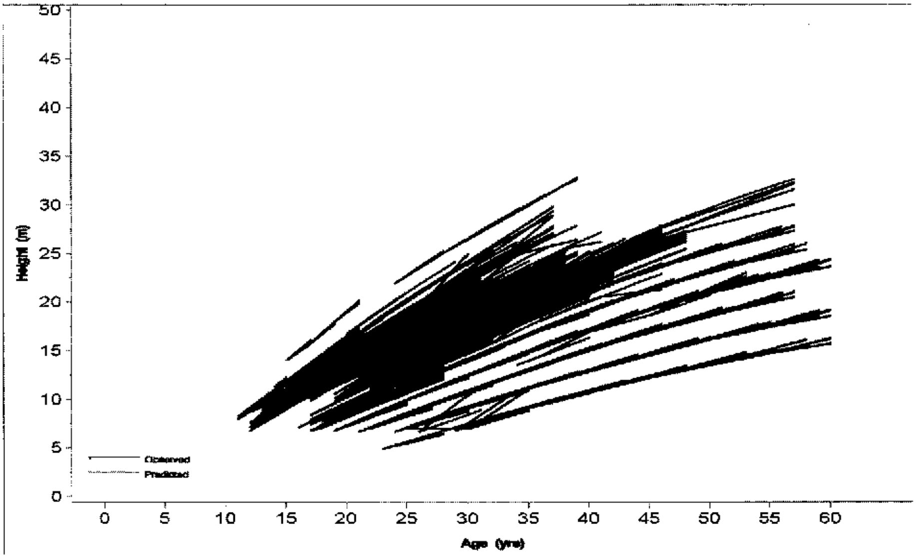

Figure 4: Sitka spruce (thinned) observed v predicted top height development.

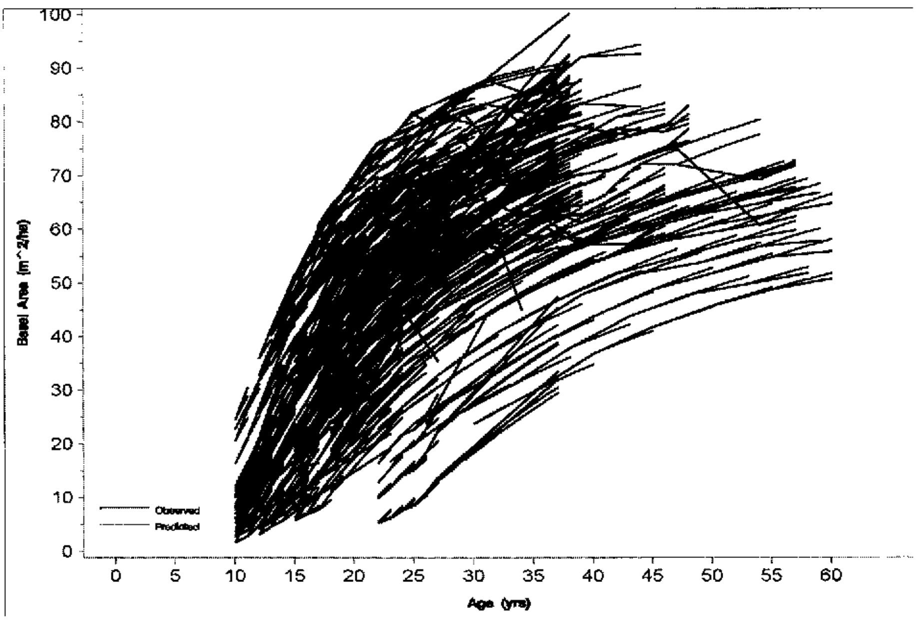

Figure 5: Sitka spruce (un-thinned) observed v predicted basal area development.

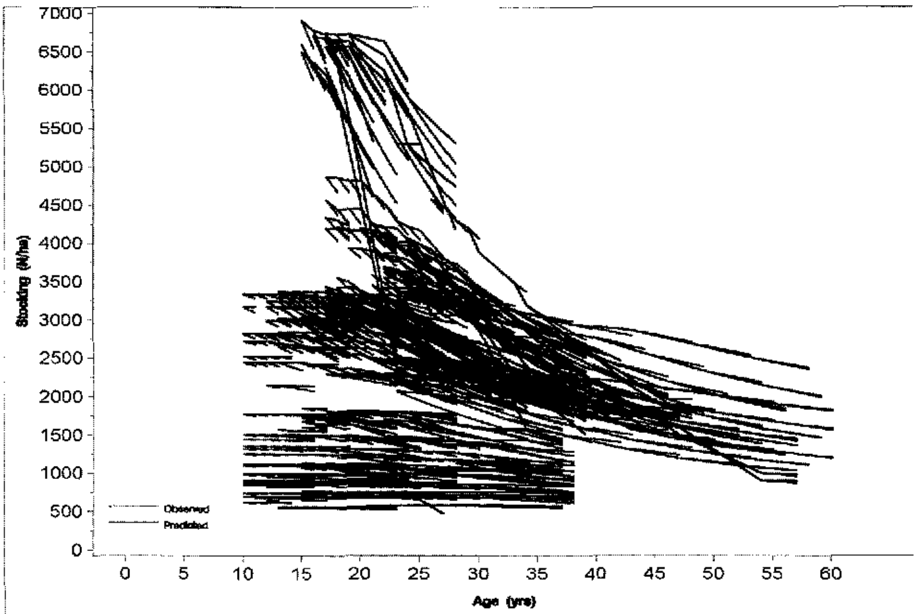

Figure 6: Sitka spruce (un-thinned) observed v predicted stocking development.

From Figures 5 & 6 it is immediately apparent that the observed basal area and stocking development from thinned stands is considerably less variable than that from un-thinned stands. Mortality in un-thinned stands tends to be clumped both spatially, and temporally.

Volume equation estimation

The explicit form of equation (9) identified by SAS® Proc Reg (SAS Institute 1990) using stepwise regression was found to be

$$V/B = \beta_0 + \beta_1 H + \beta_2 H/\sqrt{N} + \beta_3/H + \beta_4 H/N + \beta_5 100/(BH) + \beta_6 S/B + \beta_7 S^2/B$$

Where

$\beta_0 =$ 3.30847 (0.1415)
$\beta_1 =$ 0.32046 (0.0106)
$\beta_2 =$ -0.53576 (0.2815)
$\beta^3 =$ -21.31789 (0.0001)
$\beta_4 =$ 23.29623 (0.0244)
$\beta_5 =$ 0.77977 (0.1671)
$\beta_6 =$ -3.05454 (0.2538)
$\beta_7 =$ 0.12462 (0.0086)
with adjusted $R^2 = 0.9806$.

Multiplying the above equation by basal area, B, puts it in a suitable form to predict volumes for both thinned and un-thinned stands.

The equation was fitted to a dataset comprising 1676 observations that was extracted from Coillte's database. Each observation had measurements of basal area, stocking, top height, site index and volume to 7 cm small end diameter (*SED*). Some 113 observations came from the non-research database. This was used as a calibration dataset, as it is known to be free of sampling bias. A further 222 observations comprised replicated FC data to cover the shortfall of data in lower site index classes. The remaining observations came from the research database and a small external dataset known as the *paper plot* series.

The fitting strategy commenced with weight determination using equation (14). The site index available with each observation was used to determine the sampled site index distribution. Upon fitting, the relative errors with respect to the calibration data were determined. Subsequent refitting involved iterative weight adjustment in order to reduce the relative prediction errors with respect to the calibration data. The fitting procedure involved a manual search to determine weight sets that were associated with low relative prediction errors over the calibration data. The approach of treating the weights as extra parameters and using nonlinear programming techniques for parameter estimation could not be used. This approach would have tended to drive the weights associated with the research data to zero. The research data were observed over a wider range than the calibration data, and can be seen to extend the range of the calibration data, despite the quality issues.

Thinning equation estimation

The parameters in equation (11) were determined using the SAS® weighted non-linear least squares procedure, Proc Nlin (SAS Institute, 1990). The data comprised 532 observations each having basal area and stocking (before and after thinning) along with the top height. Observations from plots with systematic first thinning were excluded from the regression. Observations were assumed to be statistically independent. The model represents the *pure selection component* of any thinning (i.e. exclusive of any rack-row thinning). The fitting process was direct, as Coillte does not have any thinning data independent of those used in model fitting. Consequently, there was no basis for undertaking further model fits through weight changes.

The weights for the nonlinear regression were initially determined using equation (14). Site indices for the sampled population were obtained by union of the site indices from each thinning observation. Data was sourced from the portion of Coillte's database representing stands over a range of thinning types: light selection, systematic, selection, spaced thinnings. Additional data came from an early thinning data set representing non-systematic thinnings.

The estimated thinning equation parameters and their parenthesised standard errors are

$a = 3.140$ (0.7122)
$b = 0.1800$ (0.0414)
$c = -0.1838$ (0.0253)
$d = -0.3267$ (0.0463)

During simulations, rack-row thinning is dealt with using proportionate reduction of basal area and stocking.

Assortment equation estimation

Equation (12) was used to develop separate assortment models for thinned and un-thinned Sitka spruce stands. Parameter estimation was through maximum likelihood estimation. The likelihood function specified by Greene (1997, p. 916) was extended to the weighted form specified in Appendix 1, so as to address imbalances in volume data collection (Broad and Lynch 2006). The likelihood was maximised using the Newton-Raphson method, which functions through repeated solution of a set of linear equations. A useful property of the log likelihood function is that it is globally concave, thereby ensuring that a local optimum is a global one, and greatly facilitating the estimation of its parameters (Greene 1997). Code development was via the SAS® Interactive Matrix Language (SAS Institute 1989).

Fitting of the log-odds ratio via weighted least squares was undertaken prior to maximum likelihood estimation. This offers the advantage of furnishing starting estimates for maximum likelihood estimation. Furthermore, the diagnostics available within regression packages can be used for model identification purposes.

The assortment model for thinned stands has some 384 thinned assortment observations that were aggregated over systematic- and line-selection thinnings from research plots. An additional 70 observations came from the non-research data and the remaining 112 observations were FC data to cover the data omission with respect to lower site indices. Final parameters for the fitted model are given in Box 3 of Appendix 2. The assortment model for un-thinned stands has 522 assortment observations from research plots, 43 observations from non-research plots and 113 additional observations sourced from FC data (Forestry Commission 1981).

The strategy adopted in fitting was to calibrate with respect to the non-research data as this data set is considered bias free. The research volume data is considered to be biased due to measurement problems associated with establishing the volume/basal area regression (Broad and Lynch 2006). Consequently, weights that were initially established using equation (14) were modified on an *ad hoc* basis so as to reduce relative prediction errors with respect to the calibration data and the fitting repeated. The fitting procedure was terminated when a mean relative prediction error of 0.0065 was achieved for the calibration data. The weight modification strategy is essentially a search, with manual intervention at each iteration.

Discussion

The most serious difficulty encountered during the construction of these models was how to address the sampling biases present within the data. Broad and Lynch (2006) indicate that only one of these biases is specific to the experimental design data. Biases were introduced when the repeated measures data from replicated experiments were aggregated and the resulting panel data set considered for yield modelling purposes. The biases are a consequence of the different data requirements for yield modelling data – notably the randomisation at plot level.

The volume bias is a genuine measurement bias. In extreme cases it leads to ill-conditioning of the volume basal versus area regression line. In these cases the bias was detected at the plot level during routine validation. In these instances correction was undertaken by creating a wider volume sample diameter range through aggregating data across blocks. The full significance of the volume bias was not however appreciated until the bias of the stand level volume equation was further investigated (Broad and Lynch 2006). The use of independent calibration data, while still retaining the biased data because of its beneficial spread, and subsequently using weight adjustment during fitting has proved a suitable way to address the bias. Both volume and assortment equations were fitted using this approach.

The building of the growth component models required addressing data omission, sampling imbalances due to over and under-sampling in some site index classes, and the compromising of statistical independence between blocked plots. Only the first two of these were addressed through data addition from an external source and by employing weighted versions of García's estimation techniques. The eroding of the statistical independence between plots could be halted, for example, by using only one plot from each experiment – this is hardly a practical solution however, as it would involve not using most of the data. Another alternative solution would be to investigate error-component models to deal with the inter-plot cross-correlation. Such models are not well developed and results from using them on even well-structured data are inconclusive (Gregoire 1987).

The extant FC models were formed by aggregating stand statistics over rigidly managed stands. As such they are largely free of equation error and provided invaluable references during model construction. Use was made of them not in terms of the absolute values of their projections but rather in terms of the relativities they offer for thinned and un-thinned stands. In addition, the trend information available on differences between stands of varying site index acted as a valuable resource.

The use of top height at a specified reference age (site index) to assess site potential is based on the observation that top height development is little affected by changes in stand density through either thinning from below, or initial spacing levels. Moreover, top height development is largely independent of the timing of such silvicultural operations and consequently its adoption as a mechanism to classify site potential is widespread. By way of comparison, the related concept of yield class (m^3 ha^{-1} yr-) employed by Johnston and Bradley (1963) has strong temporal constraints in that all thinning operations are assumed as having been performed on time. Consequently, the advancement or delay of any thinning means that yield class does not conform to its usage within the FC tables.

Although the height equation is perfectly adequate for modelling top height development, the interaction of neutral (or line thinning) with top height development requires consideration. In neutral thinning, trees are removed in proportion to their relative abundance within the stand. Thus, trees that would otherwise form part of the top height determination are removed and consequently top height may be reduced immediately following a neutral thinning. This effect could also be accompanied by a subsequent loss of height growth due to the manner in which the stand is opened. Both effects could be investigated through modelling. However, under comparatively low neutral thinning intensities the influence of both effects on top height development is likely to be small. Consequently, no modifications to the top height equation have been considered.

The classification of site effects using either site index or yield class are not totally unrelated. The use of yield class to assess site quality is appealing as it is also a measure of volume productivity. Because it is difficult to measure cumulative volume production at a given age, yield class is more easily obtained through measuring a strongly correlated variable - top height. Therefore, the same primary index - top height growth - is used in both systems. The FC models are based on the observation by Eichhorn in 1904 (Assmann 1970) that the stand volume to stand height relationship is independent of site. This means differential equations could be formulated for growth projection using top height as the independent variable rather than age as was done in this work. This would overcome the static element of the FC approach.

The flexibility of dynamic models in representing stand management scenarios comes at the price of maintaining sufficient mensurational data to form the starting point (state vector) for growth projection. The FC alternative of ensuring that establishment and subsequent thinning take place to a prescribed pattern places considerable restrictions on how stands can be managed. There may also be a large opportunity cost associated with the deployment of static yield models as strict adherence to them constrains the decision set available to managers. The application of a forest planning tool should not restrict the range of silvicultural options available to managers, particularly when those decisions can have strong economic consequences. In the case of a growth model, projections should not be predicated on a particular form of stand management.

Forestry Commission models give great weight to volume maximisation as a recommended or even optimal form, of stand management. Testifying to this is the defining of yield class and marginal thinning intensity, in terms of maximum mean annual (volume) increment (MMAI). For stands producing a single valuable resource, rotation length under volume maximisation is generally longer than that under optimal economic management (assuming repeated rotations). Equality holds only if the discount rate is zero. The management of repeated rotations under optimal economic management is equivalent to maximising the present value of an annuity payable at the end of each rotation (Neher 1990). Consequently, financial returns to forest growers can usually be improved by opting for some form of optimal economic management rather than volume maximisation. Further, dynamic growth models are readily utilisable within stand- or forest-level optimisers that seek optimal economic management decisions under changing cost and revenue structures. This in turn introduces substantial freedom as to how stand- and forest-level management activities can be conducted.

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Appendix 1

Growth model

Trajectory data consists of consecutive stand measurement pairs of the form $(\mathbf{x}_1,\mathbf{x}_2)$. The scaled time interval between observations constituting a measurement pair is denoted by $\delta\tau$.

The weighted likelihood function has form

$$L = \prod_{j=1}^{n} \left[f\left(\mathbf{x}_{2j} \mid \mathbf{x}_{1j} \right) \right]^{w_j} \tag{A1}$$

where

$f(\mathbf{x}_{2j} \mid \mathbf{x}_{1j})$ is the conditional density of $\mathbf{x}_{2j}$ given $\mathbf{x}_{1j}$

w_j is the weight associated with the jth measurement pair.

Taking logarithms and substituting from Appendix expression (A2) (García 1984) and reworking García's Method I estimation technique eventually leads to the weighted log-likelihood function

$$\ln L = -\frac{1}{2}\left[\sum_{j=1}^{n} w_j \left(p \ln 2\pi + p + \sum_{i=1}^{p} \ln \hat{\sigma}_{ii}^2 \right) + \sum_{j=1}^{n} \sum_{i=1}^{p} w_j \ln R_i(\Delta\tau_j) \right] \tag{A2}$$

$$+ \sum_{j=1}^{n} w_j \ln abs\left(|\mathbf{P}|\,|\mathbf{C}|\right) + \mathbf{1}' \sum_{j=1}^{n} w_j \ln \mathbf{x}_{2j}^{\mathrm{C}} - \mathbf{1}' \sum_{j=1}^{n} w_j \ln \mathbf{x}_{2j}$$

where

$$\hat{\sigma}_{ii}^2 = \frac{\sum_{j=1}^{n} w_j \mathring{\mathbf{a}}_{ij}^2 / R_i\left(\Delta\tau_j\right)}{\sum_{j=1}^{n} w_j} \tag{A3}$$

All other notation is as specified in García's (1984) paper. Setting the weights to unity recovers García's Method I likelihood.

Assortment model
A multinomial Logit model was used as the basis for modelling assortments. The standard model has been extended to allow for weighting of observations and to permit a different number of predictors to be associated with each category.

The weighted likelihood function has form

$$L = \prod_{i=1}^{n}\left(\prod_{j=0}^{J}\Pr[Y_i = j]^{d_{ij}}\right)^{w_i}$$

where

$$\Pr[Y_i = j] = \frac{\exp(\hat{\mathbf{a}}'_j \mathbf{x}_{ij})}{1 + \sum_{k=1}^{J}\exp(\hat{\mathbf{a}}'_k \mathbf{x}_{ik})} \qquad j = 1, \cdots, J$$

$$\Pr[Y_i = 0] = \frac{1}{1 + \sum_{k=1}^{J}\exp(\hat{\mathbf{a}}'_k \mathbf{x}_{ik})}$$

$$\sum_{j=0}^{J} d_{ij} = 1$$

$$w_i > 0$$

Here d_{ij} are category weights and w_i are observation weights.

Abbreviating the probabilities P_{ik} = Pr $[Y_i = k]$ allows the gradient of the log likelihood function to be expressed as

$$\frac{\partial \ln L}{\partial \hat{\mathbf{a}}_k} = \sum_{i=1}^{n} w_i (d_{ik} - P_{ik})\mathbf{x}_{ik}$$

Similarly, the Hessian of the log likelihood has form

$$\frac{\partial \ln L}{\partial \hat{\mathbf{a}}_k \partial \hat{\mathbf{a}}'_k} = -\sum_{i=1}^{n} w_i P_{ik}(1 - P_{ik})\mathbf{x}_{ik}\mathbf{x}'_{ik}$$

and $$\frac{\partial \ln L}{\partial \hat{\mathbf{a}}_k \partial \hat{\mathbf{a}}'_l} = -\sum_{i=1}^{n} w_i P_{ik} P_{il}\mathbf{x}_{ik}\mathbf{x}'_{il} \qquad k \neq l$$

Parameter estimation is via Newton's method.

Appendix 2

Sitka spruce / Systematic and selection thinning growth model

$$\mathbf{P}=\begin{bmatrix} 1.0 & -129.8534 & -6.4478 \\ -6.8276E-4 & 1.0 & 7.0968E-3 \\ 0.0 & 0.0 & 1.0 \end{bmatrix}$$

$$\Lambda=\mathrm{diag}(-1.393239, -0.427852, -1.0)$$

$$\mathbf{P}^{-1}=\begin{bmatrix} 1.0973 & 142.4860 & 6.0639 \\ 7.4918E-4 & 1.0973 & -2.9566E-3 \\ 0.0 & 0.0 & 1.0 \end{bmatrix}$$

$$\mathbf{C}=\begin{bmatrix} 0.8291 & 1.0813\mathrm{E}-2 & 0.2445 \\ -3.0276E-3 & 7.8987\mathrm{E}-2 & -4.0730E-3 \\ 0.0 & 0.0 & 0.624157 \end{bmatrix}$$

$$\mathbf{C}^{-1}=\begin{bmatrix} 1.2055 & -0.1650 & -0.4733 \\ 4.6208E-2 & 12.6539 & 6.4474E-2 \\ 0.0 & 0.0 & 1.602160 \end{bmatrix}$$

$$\mathbf{a}=\begin{bmatrix} 102.0838 \\ 1.4609 \\ 11.3990 \end{bmatrix}$$

$$t_0=-0.75$$

$$\gamma_1=-3793.0663 \qquad \gamma_2=0.02019244$$

Box 1: Sitka spruce (thinned) growth component coefficients.

Sitka spruce / un-thinned growth model

$$\mathbf{P}=\begin{bmatrix} 1.0 & 127.5287 & -16.4235 \\ 6.1473E-4 & 1.0 & -3.2033E-2 \\ 0.0 & 0.0 & 1.0 \end{bmatrix}$$

$$\Lambda=\mathrm{diag}(-0.724367,\ -0.285728,\ -1.0)$$

$$\mathbf{P}^{-1}=\begin{bmatrix} 1.0851 & -138.3768 & 13.3880 \\ -6.6702E-4 & 1.0851 & 2.3803E-2 \\ 0.0 & 0.0 & 1.0 \end{bmatrix}$$

$$\mathbf{C}=\begin{bmatrix} 0.8226 & -7.0468E-3 & 0.4482 \\ -1.2591E-2 & -0.1874 & 0.1725 \\ 0.0 & 0.0 & 0.624157 \end{bmatrix}$$

$$\mathbf{C}^{-1}=\begin{bmatrix} 1.2149 & -4.5680E-2 & -0.8598 \\ -8.1621E-2 & -5.3327 & 1.5325 \\ 0.0 & 0.0 & 1.602160 \end{bmatrix}$$

$$\mathbf{a}=\begin{bmatrix} 248.4541 \\ 0.7077 \\ 11.3990 \end{bmatrix}$$

$$t_0=-0.75$$

$$\gamma_1=-2344.7663 \qquad \gamma_2=0.02390764$$

Box 2: Sitka spruce (un-thinned) growth component coefficients.

Sitka spruce / thinned assortment equation

Category 1 (>= 20 cm SED); parameters $\hat{\mathbf{a}}_1$

INTERCEPT	10.3553
$1/(D_0/100)$	-2.4317
$D_0 * D_0 * H/10000$	-0.3571
$D_0 * D_0 / H$	0.0049
S	0.0929
$D_1 - D_0$	-4.5091
$(D_1 - D_0)$^2	0.4267
$(D_1 - D_0)/(H/10)$	4.6278
$1/((D_1 - D_0)*H)$	-7.1732
$H/(100*(D_1 - D_0)$^2)	0.1023
$(B_0 - B_1)$	0.3142
$(N_0 - N_1) / 1000$	-8.1327

Category 2 ([14, 20) cm SED); parameters $\hat{\mathbf{a}}_2$

INTERCEPT	5.1717
$1/(D_0/100)$	-0.6686
$D_0 * D_0 / 100$	-0.0720
$H/\sqrt{D_0}$	-0.2968
$D_0 * D_0 * H/10000$	-0.0945
$1.0 / ((D_0 / 100)*(H/10))$	-0.2310
S	0.0520
$D_1 - D_0$	-0.5238
$(D_1 - D_0)$ ^ 2	0.1102
$(D_1 - D_0)/(H/10)$	-0.3643
$B_0 - B_1$	0.1351
$(N_0 - N_1) / 1000$	-2.0790

Box 3: Thinned Sitka spruce assortment equation.

Sitka spruce / un-thinned assortment equation

Category 1 (>= 20 cm SED); parameters $\hat{\mathbf{a}}_1$

INTERCEPT	3.2721
$1/(D_0/100)$	0.6276
D_0/H	2.9686
$H/\sqrt{D_0}$	-0.8298
$1/((D_0/100)*(H/10))$	-1.9552
S	-0.0111
$10*D_0/N_0$	-1.1417
D_0*D_0*H/N_0	0.0128
B_0	-0.0052

Category 2 ([14, 20) cm SED); parameters $\hat{\mathbf{a}}_2$

INTERCEPT	-27.6178
D_0	1.9530
$1/(D_0/100)$	2.2596
$H/\sqrt{D_0}$	-1.3761
$D_0*D_0*H/10000$	1.1733
$1/((D_0/100)*(H/10))$	-0.9512
S	0.0090
$10*D_0/N_0$	-0.1599
$100*B_0/N_0$	-4.6630

Box 4: Un-thinned Sitka spruce assortment equation.

Panel data validation using cross-sectional methods

Lance R. Broad[a] and Ted Lynch[b]

Abstract

An examination of the suitability of an Irish Sitka spruce research panel data set for growth modelling purposes was undertaken. The panel data set arose from several repeated measurements in replicated field experiments. When being considered as data for yield modelling several difficulties arise. Simple histograms comparing sampled plots and the underlying forest estate demonstrated a sampling imbalance - whereby site index classes for sampled plots misrepresented the population. The spatial proximity of established plots also meant there was a lack of randomisation at the plot level, which eroded statistical independence between plots and increased plot cross-correlations. However, the availability of independent, non-research volume data permitted the construction of stand-level volume equations for both research and non-research stands. Observed differences in volume equation residuals for research thinned and unthinned stands were then explored. Thinning effects, volume equation inadequacy, or other sampling biases were considered as potential candidates to explain residual differences. It was found that the differences were consistent with a form of sampling bias when measuring volume sample trees. These validation techniques have led to a better understanding of the research data set.

Keywords: Growth modelling, panel data, Sitka spruce, validation.

Introduction

Permanent sample plots are the most common source of data for studies concerning forest growth and yield. Data from permanent sample plots have both spatial and time components. The spatial component is associated with the location of plots within a forest estate, which collectively give rise to a cross-sectional sample at a given point in time. The temporal component refers to repeated measurement of permanent sample plots, giving rise to a longitudinal sample. Data from permanent sample plots that combine cross-sectional and longitudinal samples are known as panel data. Forestry panel datasets tend to be more complicated than those found within econometric literature. The reason is that the longitudinal sections, or time between samples, in forestry data sets are often not evenly spaced.

Standard validation of forestry panel data usually progresses via a range of *ad hoc* computer based techniques that examine both longitudinal attributes, such as the time series associated with individual tree diameters in a plot, and cross-sectional aspects, such as rates of taper along volume sample trees. Standard validation tests tend to mirror the structure of the data, in that checks perform tests on the cross-sectional and longitudinal portions of the panel data. Validation of data is usually performed prior to their use in the fitting of equations.

[a] Technical Forestry Services, New Zealand.

[b] Coillte Research and Development, Newtownmountkennedy, Co Wicklow, Ireland (corresponding author, ted.lynch@coilte.ie).

Obtaining reliable panel data relies as much on good measurement practice as it does on a set of validation tests. Good measurement, data entry and transcription practices (when used), can help ensure a clean run through validation testing. However, it is not generally possible to formulate one set of validation tests that is sufficiently comprehensive to constitute the definitive set of tests for all intended use of forestry panel data. Consequently, validation tests tend to be specific, with consideration given to the prevalent form of stand management.

The standard type of validation tests, focusing on cross-sectional and longitudinal attributes, are not directed towards detecting forms of sampling bias that are associated with the initial creation of the permanent sample plots. Even the cross-sectional aspects of such testing are typically conducted within-plot and are not focused towards using inter-plot information. Similarly, longitudinal testing is generally conducted within-plot. However, many forms of sampling bias arise through a lack of appropriate randomisation. Consequently, bias detection requires an assessment of the underlying sample survey design structure to determine how randomisation issues have been approached and implemented.

This work sets out an investigation of the suitability of an Irish Sitka spruce panel data set for growth modelling purposes. This required an investigation the data set for the presence of sampling bias, through deploying both graphical and analytical techniques. The investigation was performed largely, although not totally, at the cross-sectional level.

Data and methods

Data provenance

Coillte Teoranta (the Irish Forestry Board) maintains the most extensive database on Sitka spruce (*Picea sitchensis* (Bong.) Carr.) in the Irish Republic. Initial measurements on research permanent sample plots used imperial units. In 1972 the metric system was adopted; subsequent measurement continued in metric, the original data were not generally converted. The database includes many silvicultural thinning and spacing trials that have been conducted during the period 1963 to 2001. Data used in modelling within this study were measured during the period 1972 to 2001. The database was computerised in 2000 using Microsoft Access®, thereby allowing investigation through database queries. Other code components have facilitated assembling of data required for growth and yield studies. Table 1 contains a summary of the Sitka spruce data.

In 2003, Coillte established within its production stands a small cross-sectional sample that consisted of volume data only. These are the non-research data within the study - and comprise some 70 observations from thinned stands and 43 from unthinned stands. The location of the non-research plots was determined using a systematic sample survey design. Data were collected according to generally recognised sampling practices – particular attention was given to the collection of volume sample trees. Although designed as a systematic sample it was treated as a random sample in the study. The prospect of there being any form of cyclical bias is considered remote, but since several of the plots were measured in the same dormant season there is a possibility of cross-plot correlation due to climatic effects.

Table 1: Coillte's Sitka spruce dataset.

	Sampling method	Variable(s)[1]	Quality	Sample size n
Non-research data (Thinned)	Systematic Sampling	dbh, N, H and sectional volumes (cross-sectional data set)	Good	70 (volume)
Non-research data (Unthinned)	Systematic Sampling	dbh, N, H and sectional volumes (cross-sectional data set)	Good	43 (volume)
Estate data (Thinned)	Total enumeration	Site index (cross-sectional data set)	Good	27,887 (site index)
Estate data (Unthinned)	Total enumeration	Site index (cross-sectional data set)	Good	16,330 (site index)
Research data (Thinned)	Plots in replicated field experiments	dbh, N, H, and sectional volumes (panel data set)	Stat. ind. compromised	819 (volume)
Research data (Unthinned)	Plots in replicated field experiments	dbh, N, H and sectional volumes (panel data set)	Stat. ind. compromised	425 (volume)

[1] *dbh: diameter at breast height (1.3 m above ground level)*
N: stems per plot
H: top height
Site index: top height (m) at age 30 (elapsed growing seasons since planting)

Further site index data were available at the sub-compartment level (the smallest unit of area that can be considered homogeneous for management purposes) across the entire Coillte estate. Consequently they give the most accurate site index representation possible for the estate[2], and are termed estate data.

Coillte's research data base was initially established as a set of spacing and thinning trials, which were mostly established using a randomised block design. Blocked plots were repeatedly measured, thereby creating a panel data set. While treatments were randomly assigned within blocks, having plots in close physical proximity to each other led to highly correlated growth model residuals.

The existence of the non-research and estate data sets allowed comparisons with the cross-sectional component of the research panel data set to be made. Elucidating the cross-sectional nature of the research data can, in some circumstances, also lead to an understanding of its longitudinal behaviour.

[2] At the time of writing Coillte's forest estate had 44,217 sub-compartments, some 27,887 managed as thinned stands with the remainder unthinned.

Graphical analysis

Volume datasets for thinned and unthinned plots were extracted from the research database: the thinned dataset had 819 plot-level volume observations, while the unthinned set had 425. The greater number of thinned observations was due to availability of observation data both before and after each plot was thinned. Site index was also available for each plot.

The volume samples were part of a larger data set that includes plot re-measurement data, allowing construction of growth trajectory data. The volume samples are a subset of those available within the research database. Specifically, they are the volume samples associated with the growth trajectory data. In this sense, they represent the cross-section associated with the panel data set.

An obvious requirement of any sampling design that seeks to provide data for yield modelling is that plots should exist over the range of site indices found within the forest estate where the model is to be applied. Similarly, the frequency with which plots appear in site index classes should, by and large, be the same as the frequency that estate stands appear in that site index class. Conformity to these requirements is easily checked by plotting appropriate site index graphs. Site index histograms for thinned and unthinned stands were therefore plotted for research and estate data (Figure 1).

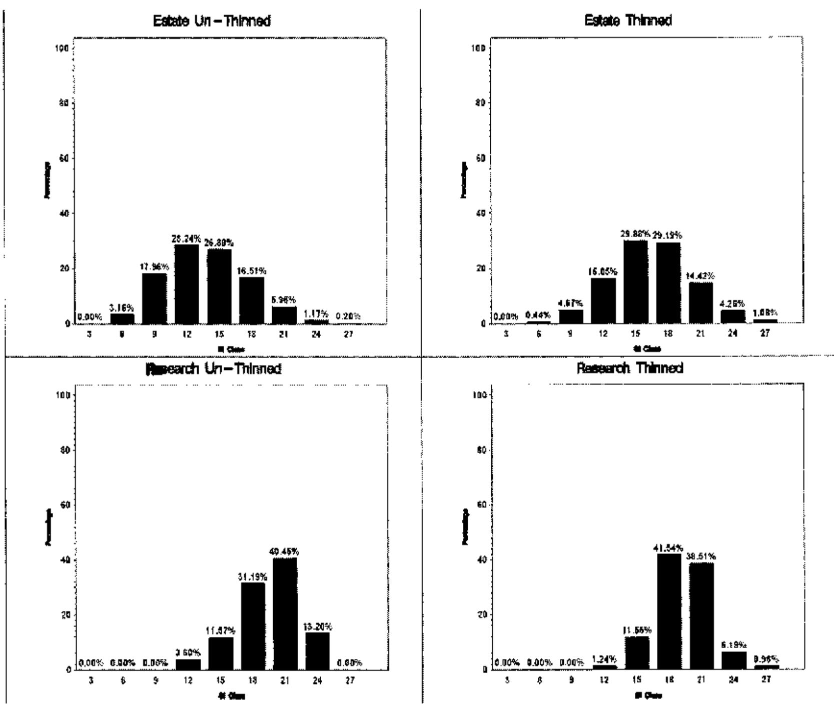

Figure 1: Site index distributions for (clockwise from bottom left) Research Unthinned, Estate Unthinned, Estate Thinned and Research Thinned.

It is apparent from a comparison of research and estate site index histograms in Figure 1 that research plots have been located predominantly in higher site index stands and there were no research (thinned or unthinned) plots in the two lowest site index classes that occurred within Coillte's estate.

Corroborative evidence as to the difference in site index distribution between research and estate data was obtained by testing the multinomial hypothesis $H_0 : p_i = p_i^o$ versus $H_0 : p_i \neq p_i^o$ for some i. Here p_i^o are the proportions appearing in each site index in the estate histogram of Figure 1, while p_i are the corresponding proportions appearing in the research histogram. The test was conducted using Pearson's chi-squared test with test statistic

$$Q_k^0 = \sum_{i=1}^{k+1} \frac{(N_j - np_j^o)^2}{np_j^o}$$

having k degrees of freedom (Mood et al. 1974). Strictly, the test requires independence of the underlying multinomial trials, a requirement that was not fully met due to the layout out of research plots within the experiment design blocks. Performing the test for the thinned crop was $P(\chi^2_7 > 625.5) < 0.001$ and for the unthinned crop $P(\chi^2_7 > 1648.2) < 0.001$. Figure 1 and the chi-squared tests therefore jointly indicated that the site index distribution within the experiment plots was not reflective of site index across the Coillte estate.

The graphical analysis identified that the selection of sites for field experiments was biased towards higher productivity sites. Site index is not influenced by thinning practice (inclusive of no thinning) when thinning is conducted from below. Consequently many of the plots in experiments would have similar site indices due to the spatial proximity of the plots. This also suggests a lack of randomisation at the plot level.

The overall sampling design for the experiments has not been recorded. It is highly unlikely that the pattern of site indices indicated within the research data of Figure 1 would emerge from a sampling design based on a simple random sample of plots. More sophisticated, randomly based plot sampling designs, such as sampling via a probability proportional to size within a site index class, would serve to lessen the probability of observing the outcome associated with the research data in Figure 1. These statements must be qualified, in that the establishment of permanent sample plots, for reasons of limitation of resources, generally takes place over a number of years. Forest estates can change over time with respect to their site index distributions, depending on factors such as soil fertility, effects of multiple rotations, and land transfers to, and from, other land uses.

A number of methods are available to address data imbalance. Provided data exist within all site index classes, weighting can be used to when fitting models. However, where classes are not represented in the sample, then data imbalance can only be addressed by using additional data obtained by further sampling, or by use of data from an external source.

Quantitative techniques for examining a panel dataset are applicable when either an independent panel or a cross-sectional dataset exist; these allow equation fitting and model comparisons to be made. Here, volume equations over the research and non-research cross-sectional data were used to further examine the cross-sectional structure of Coillte research database.

Volume equation analysis

The volume equations used come from a general class of volume/basal area quotient equations introduced by García (1984). The equations are fitted in quotient form so as to improve error variance homogeneity. Their general form is

$$\frac{V}{B} \cong \beta_0 + \sum_{i=1}^{n} \beta_i \, g_i(B, N, H, S) \qquad (1)$$

Where

$\beta_0, \beta_1, \ldots, \beta_n$ is a set of parameters, $g_i(B, N, H, S)$ is a predictor formed from its arguments basal area B (m^2 ha^{-1}), stocking N (stems ha^{-1}), top height H (m) and site index S (top height (m) at age 30), through the operations of multiplication, division, taking a power or multiplication by a constant.

Here site index (S) may be used to account for any site effects (García personal communication). Provided the predictors are formed as indicated above, the resulting equation will always be linear in its parameters. Stepwise regression is then a particularly useful technique for model identification and fitting purposes.

Fitting equation (1) to the combined research thinned and unthinned data resulted in the model specified in Table 2.

The model has an R^2 of 0.9627 and an adjusted R^2 of 0.9625.

The dynamic re-weighting scheme available within SAS® PROC REG (SAS Institute 1990b) was used to screen observations during model fitting. Observations having an absolute studentised residual of more than 3 were excluded from model fitting – this resulted in 14 observations being removed.

The model appears under a range of fitting diagnostics to be adequate but upon closer scrutiny of the volume predictions, biases are observed as described below.

Table 2: Sitka spruce research data – volume/basal area quotient regression.

Variable	*Parameter*	*Std Error*	*Pr > |t|*
Intercept	*4.11729*	*(0.3627)*	*< 0.0001*
H	*0.26687*	*(0.0144)*	*< 0.0001*
H/√N	*4.71047*	*(0.5277)*	*< 0.0001*
1/H	*-33.32451*	*(2.6576)*	*< 0.0001*
H/N	*-64.28313*	*(7.8327)*	*< 0.0001*
*100/B*H*	*1.00465*	*(0.3152)*	*0.0015*
S/B	*1.69270*	*(0.4542)*	*0.0002*
*S*S/B*	*-0.09036*	*(0.0139)*	*<0.0001*

Applying the equation specified in Table 2 to predict volumes (to 7 cm small end diameter (SED)) for each unthinned research observation results in the predictions of Table 3.

Here V7 denotes mean observed stand volume to 7 cm SED, V7hat is estimated mean stand volume to 7 cm SED, V7rsd denotes the mean residual when estimating to 7 cm SED. Finally, V7rpe is relative prediction error for V7 being calculated as the mean of quotients of the form (V7-V7hat)/V7. For the unthinned research data, the result indicates that there is a 2.33% over-estimation of volume to 7 cm SED as assessed by a mean relative prediction error (equivalently mean of ratios).

Applying the equation in Table 2 to predict volumes for the research thinned stands leads to the results in Table 4.

For the research thinned data there was a 0.37% under-estimation of volume to 7 cm SED via a mean relative predictive error statistic. It is apparent that the research equation in Table 2 is better at predicting the thinned data than the unthinned data. This is a reflection of the observation weighting employed. During fitting some 819 thinned and 425 unthinned observations were used.

Having observed the biases arising from the research volume equation the question arises as to whether they are statistically significant? The lack of statistical independence within the research data (see Table 1) precludes the direct testing of biases via volume equation parameters. Such an approach would test for common parameters for thinned and unthinned stand volume equations. A probabilistic analysis can, however, be conducted using a related set of findings. The same pattern of biases was observed when (uncalibrated) volume equations were fitted to research data from four additional species: Douglas fir, lodgepole pine, Norway spruce and Scots pine (unpublished work). In each case, the thinned volume observations were, on average, under-predicted, while the unthinned observations were over-predicted.

Table 3: Research unthinned data mean predictions.

Variable	*Observations*	*Mean*
V7	*425*	*364.6903*
V7hat	*425*	*373.5528*
V7rsd	*425*	*-8.8625*
V7rpe	*425*	*-0.0233*

Table 4: Research thinned data mean predictions.

Variable	*Observations*	*Mean*
V7	*819*	*312.3422*
V7hat	*819*	*309.9420*
V7rsd	*819*	*2.4003*
V7rpe	*819*	*0.0037*

With respect to each volume basal area quotient equation fitted over thinned and unthinned observations, the sum of the theoretical residuals may be partitioned as

$$\sum_i \varepsilon_i = \sum_j \varepsilon_j + \sum_k \varepsilon_k$$

where the first summation on the right is taken over the thinned observations and the second over the unthinned. The observed residuals on any volume basal area quotient equation are required to sum to zero. This follows from the normal equation associated with the constant parameter (see Seber 1977, p 47). A null hypothesis of there being no difference in the predictive ability of each volume equation over its respective thinned and unthinned stands requires the expected values of the sum of theoretical residuals be zero i.e.

$$E(\sum_j \varepsilon_j) = 0 \quad \text{and} \quad E(\sum_k \varepsilon_k) = 0$$

By appealing to the central limit theorem (Capinski and Kopp 1999) we can assume that the theoretical residual sums

$$\sum_j \varepsilon_j \quad \text{and} \quad \sum_k \varepsilon_k$$

are normally distributed. Normal distributions are symmetric and consequently the mean, median and mode assume a common value of zero. From normal distribution theory we can make the statement

$$P[\sum_j \varepsilon_j > 0] = 1/2$$

or equivalently in terms of the mean

$$P[n_1^{-1} \sum_j \varepsilon_j > 0] = 1/2$$

where n_1 is the number of thinned observations. A similar statement holds with respect to sum and mean for the unthinned errors.

The observed mean residuals for any volume basal area quotient regression, although theoretically correlated, should also tend to follow a normal distribution. Consequently, we anticipate the observed mean residuals for thinned and unthinned stands to be normally distributed with mean, median and mode of zero. It is important to note that the probability of $^1/_2$ that the observed residual sum, or mean, exceeds the median (50% quantile) is the same for each of the five volume equations. Given that all five equations examined had observed thinned mean residuals exceeding zero, then under the null hypothesis the probability of this event happening on the basis of chance is determined from the binomial distribution as . This differs markedly from the observation that 100% of trials had thinned mean residuals above their median value, and is strongly suggestive of the presence of bias associated with thinned and unthinned predictions.

The non-research data do not suffer from the same lack of statistical independence as do the research data. In terms of plot selection these data are known to have been collected in a manner that was virtually equivalent to a random sample. Volume sample trees were randomly selected across the range of merchantable trees. The non-research data consist of a volume cross-section over some 70 thinned plots and 43 unthinned plots.

In Table 5 results are presented from fitting a volume/basal area quotient regression to non-research volume observations.

The model was fitted over the non-research thinned and unthinned stand volume observations. It has an R^2 of 0.9627 and an adjusted R^2 of 0.9625.

The non-research volume equation allowed the construction of Table 6, which shows mean observed, predicted, residual and relative prediction error values for thinned stands.

The mean observed, predicted, residual and relative prediction error values for the volume equation for unthinned non-research stands are shown in Table 7.

The hypothesis model given in Table 5 can be tested against a maximal model, where separate volume equation parameters are fitted for thinned and unthinned stands. The test provides an indication as to whether separate regressions are required for volume predictions in thinned and unthinned stands.

Table 5: Non-research data – volume/basal area quotient regression.

Variable	*Parameter*	*Std. Error*	*Pr > |t|*
Intercept	*0.92527*	*(0.4201)*	*< 0.0001*
H	*0.41616*	*(0.0143)*	*< 0.0001*
*N*H/1000*B*	*-1.97212*	*(0.2799)*	*< 0.0001*
B/H	*0.19608*	*(0.0575)*	*< 0.0001*

Table 6: Non-research thinned data mean predictions.

Variable	*Observations*	*Mean*
V7	*70*	*394.2157*
V7hat	*70*	*393.9792*
V7rsd	*70*	*0.2364*
V7rpe	*70*	*-0.0042*

Table 7: Non-research unthinned data mean predictions

Variable	*Observations*	*Mean*
V7	*43*	*378.5654*
V7hat	*43*	*379.1120*
V7rsd	*43*	*-0.5466*
V7rpe	*43*	*-0.0050*

Table 8: F-test of common volume equation parameters for thinned and unthinned stands.

Source of variation	*degrees of freedom*	*sum of squares*	*mean square*
Resid. hypothesis model	*109*	*30.5236*	
Resid. maximal model	*105*	*29.5297*	*0.2812*
Difference for test	*4*	*0.9939*	*0.2485*

From Table 8 the quotient of the Difference mean square and the Maximal Model Residual mean square is 0.8835 and is distributed as $F_{4, 105}$. The test indicates that the null hypothesis of a common volume equation for thinned and unthinned stands cannot be rejected.

The conditions required for implementation of the test in Table 8 can be questioned (see Discussion). However, further support for the test result comes from the comparatively small magnitudes of the biases and the near zero relative prediction errors in Tables 6 and 7.

Discussion

The statistical test used for the non-research volume observations requires statistical independence between observations on plot volume. Also required is homogeneity of error variance. It is possible that the volume equation residuals would exhibit some degree of auto-correlation associated with within plot predictions over small time intervals in the absence of thinning. Cross-correlation effects between plots arise largely through climatic effects and are most pronounced when plots are re-measured in the same year. Factors that should reduce the impact of the correlation structure are longer periods between subsequent re-measurement of plots and the fact that not all plots are measured in the same year. The effect of the correlation structure has been ignored here.

A more comprehensive analysis would involve building an error component model that included serial- and cross-correlation terms and testing the significance of these effects. In a study of error component models for forestry yield models Gregoire (1987) found that ordinary least squares had lower prediction errors than models fitted with error components attached. Gregoire's work suggests that it may be difficult to formulate appropriate error component models.

The biases found in the research data volume predictions are likely to be consistent with any of the following causes:

1. there is a positive thinning effect which occurs when thinning is properly performed,
2. some form of volume equation inadequacy (other than a thinning effect or sampling bias which can lead to volume equation difficulties) or
3. there is a volume sampling bias.

It is possible that these causes may act in concert. However, the investigation was restricted to single effects under the assumption – that, at most, one of these causes is active. This restriction is very stringent but it does facilitate discussion of the possible causes. It can be argued that the likelihood of more than one cause being active is small.

Any thinning effect is envisaged to act through facilitating stem diameter growth above the point of dbh measurement, and result in higher stem volumes for thinned stands. The mechanism for any such effect is envisaged as a photosynthetic response of the remaining tree crowns to higher light intensity following removal of competition in thinning. Thinning in the research plots was closely specified and supervised to ensure consistent levels of thinning over plots.

If a thinning effect were the cause of the differences observed in the research data then it should also express itself within the non-research data and be capable of detection using statistical tests. The fact that no statistical difference was observed between thinned and unthinned volume equations for the non-research data suggests however that a thinning effect cannot be active.

If there are inadequacies in the volume equation that led to the observed differences in the research data then these should be apparent when fitting volume equations to the non-research data and again be capable of detection using statistical tests. The lack of statistical difference between thinned and unthinned volume equations for the non-research data suggests that the argument for volume equation inadequacy is not strong. Further support for the volume equation comes from this class of equation being widely used for both thinned and unthinned stands without encountering bias problems (García 1984, 2003).

The suggested cause of additional volume sampling bias is most likely associated with the subjective selection of larger volume sample trees. Selecting larger volume sample trees leads to a larger mean volume per tree, which in turn leads to, a larger plot volume or volume per hectare, when multiplied by the appropriate stocking. Stated alternatively, any selection bias towards larger volume sample trees will be reflected in the parameters of the individual tree volume versus basal area straight line (regression) used to calculate mean volume per tree, and also in the parameters of the volume/basal area quotient regression used to calculate volume per hectare.

Plot location could also act as a form of sampling bias contributing to the differences in volume equation residuals. Many of the experiments used as data sources were established using replicated experiment designs. Any plot selection bias in this instance would be expressed at the block level (block selection bias) and possibly even the experiment level.

If a sample bias occurred with respect to research data it would not be anticipated to occur with non-research data. Plot selection for the non-research data used a systematic sampling design. Although such designs are capable of admitting cyclical forms of bias, their behaviour is expected to closely parallel a fully randomised design. Moreover, the volume sample trees for the non-research plots were selected across the range of observed diameters, thus ensuring acceptable determination of the parameters in the individual tree volume versus basal area regression.

The statistical test conducted on the non-research volume equation is consistent with a sampling bias not being present, but suggests a sampling bias in the research volume data.

Although this analysis suggests a bias in the research volume data it does not provide a definitive indication as to its source. In an endeavour to trace the source of the bias the relative prediction errors for the research thinned data were calculated and subsequently sorted. Of particular interest were observations with observed values (plot volumes as determined through sectional measurement and volume/basal area regression) being under-predicted by the volume equation, as these may suggest that the observed values are too high. These observations were examined to determine the range of the breast height diameters associated with the volume sample trees compared with the breast height diameter range for the crop trees (Table 9).

Table 9: Crop and volume sample breast height diameter range data[1].

		Sample		*dbh (cm)*		
Plot	*Year*	*Crop*	*Volume*	*Min*	*Max*	*Range*
CCA057901	*1979*	*MC*		*6.4*	*20.2*	*13.8*
	1979	*TH*		*7.2*	*16.0*	*8.8*
	1979		*TH*	*11.1*	*15.2*	*4.1*
CCA057910	*1978*	*MC*		*7.2*	*18.5*	*11.3*
	1978	*TH*		*7.5*	*17.5*	*10.0*
	1978		*TH*	*9.4*	*14.8*	*5.4*
CCA057902	*1978*	*MC*		*5.7*	*16.8*	*11.1*
	1978	*TH*		*8.0*	*17.5*	*9.5*
	1978		*TH*	*9.9*	*14.5*	*4.6*
CCA057909	*1978*	*MC*		*8.2*	*17.8*	*9.6*
	1978	*TH*		*8.1*	*17.5*	*9.4*
	1978		*TH*	*10.1*	*15.2*	*5.1*
CCA057906	*1978*	*MC*		*5.9*	*17.8*	*11.9*
	1978	*TH*		*7.1*	*16.9*	*9.8*
	1978		*TH*	*9.6*	*15.9*	*6.3*
CAL018109	*1980*	*MC*		*2.1*	*16.9*	*14.8*
	1980	*TH*		*7.7*	*13.8*	*6.1*
	1980		*TH*	*8.0*	*14.1*	*6.1*
CAL018108	*1980*	*MC*		*7.3*	*15.3*	*8.0*
	1980	*TH*		*3.5*	*13.5*	*10.0*
	1980		*MC*	*9.0*	*13.9*	*4.9*
	1980		*TH*	*8.3*	*12.2*	*3.9*

[1] *MC (main crop), TH (thinning)*

The results in Table 9 were obtained from the first 11 plot volumes considered after sorting on relative prediction error. It is apparent that the diameter range associated with the volume sample trees is generally small when compared with the range of diameters associated with either the main crop or the thinning trees. In addition, an examination of the dbh measurements for the volume sample trees invariably shows that they have been sampled towards the upper end of the plot distribution. The first six plots in Table 12 contain information for the first year of neutral systematic thinnings. The volume sample trees are for the thinned crop portion, but in this context they are also used to calculate volumes for the main crop. The lack of adequate range for dbh measurements illustrated above is not confined to neutral thinning schemes as the last observation in Table 9 illustrates. Nor is it confined to thinned plots as the same problem can be identified in unthinned plots.

The impact of sampling volume sample trees over a restricted range can be understood by examining the variance associated with parameter estimates in the tree volume v basal area regression. The equation has form:

$$y_i = \alpha + \beta x_i + \varepsilon_i \qquad E(\varepsilon_i) = 0 \qquad E(\varepsilon_i^2) = \sigma^2$$

Where the dependent variable y_i denotes tree volume and the independent variable x_i denotes tree basal area. The variance associated with the intercept parameter is

$$Var(\hat{\alpha}) = \frac{\sigma^2 \frac{1}{n} \sum_{i=1}^{n} x_i^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

and that of the slope parameter is

$$Var(\hat{\beta}) = \frac{\sigma^2}{\sum_{i=1}^{n} (x_i - \bar{x})^2}$$

Parameter standard errors may be obtained by taking square roots of the above expressions. Larger standard errors are directly linked to sampling over a restricted dbh range as they become larger as the denominator expressions become smaller. The denominators are an expression that depends on the range of the sampled data. The denominators can be maximised by taking data at the extremes of the ranges. Choosing half the values at each end of the range results in a D-optimal design (Seber 1977). Although sampling at either extreme of the range results in a D-optimal estimation of the slope and intercept parameters, this approach faces a difficulty within a forestry setting. Merchantable trees have a limiting lower dbh and non-merchantable trees may fall below this. It is sensible to restrict the volume sample trees to merchantable trees. At each end of the merchantable dbh range there may be abnormal trees either suffering from suppression at the lower end, or having enhanced upper stem diameters at the upper dbh range. Consequently, a more pragmatic approach may be to select volume sample trees randomly across the merchantable range. The important point is to sample across the merchantable range.

Given the information to hand, therefore, it is possible to conjecture that the observed biases found in volume equation residuals arise through taking volume sample trees towards the upper end of the dbh distribution. For thinned stands, it is envisaged that the selection has also been biased towards trees with enhanced upper-stem diameters. This conjecture could account for the pattern of observed biases.

A further issue relating to Coillte's database is the intention of the original design versus its intended use in a yield modelling setting. The database is aggregated, in the main, from repeated measurements in replicated field experiments that were originally designed to examine thinning and spacing effects. These designs are capable of analysis using mainly analysis of variance techniques (e.g. split-plot or repeated measures analysis) for analysis of cumulative and incremental growth. In the experiment design, treatment combinations are randomised to plots, within homogenous blocks. This allows more accurate and precise treatment comparisons to be made, as biases and error variances are reduced. In the context of yield modelling, however, longitudinal observations are made on plots that are treated as being statistically independent. True statistical independence will never hold in a forestry context as different plots are always subject to similar climatic effects over any given time period.

Even if the established set of experiments were randomly located across the Irish forest estate, the set of plots within them would not be. Blocking plots in the experimental design setting requires homogeneity within blocks – a desirable feature when detecting treatment differences. Whereas blocking, in terms of yield modelling, restricts randomisation at the plot level, increases the cross-correlation between plots, and further erodes statistical independence between plots, which is already compromised through climatic effects. Parameter estimation techniques for modelling growth equations are also compromised in that the vast majority of growth component fitting techniques are developed around the assumption of statistical independence between plots.

The sampling biases considered impact on the panel data set in different ways. The impact of selecting volume sample trees over a limited diameter range is purely cross-sectional in nature. In terms of fitted models this would affect volume and assortment equations. The impact of blocking plots impacts on all fitted models as does the absence of data identified through graphical analysis.

These volume sample tree result has been deduced by undertaking comparative statistical tests and making reasonable assumptions as to how those tests should behave between research and non-research data sets. Detection of the plot cross-correlation result arises through appreciating the different requirements in assembling data for treatment comparison and yield modelling purposes.

It is important to realise that the data omission problem and the increased plot cross-correlation issue are not associated with the set of experiments, per se, rather they arise when the repeated measurements are aggregated across experiments to form a panel data set - the experiment data have only been shown to be deficient with respect to the estimation of plot volumes. Further, aggregation across valid repeated measures experimental design data does not guarantee the creation of a valid panel data set useful for yield modelling purposes.

The prospect of a thinning effect giving rise to increases in upper-stem diameters would have implications for growth modelling in that it suggests some measure of upper-stem development would be required to fully account for stand structure and growth. If higher upper-stem diameters were observable through cross-sectional sampling then there should be some associated behaviour in the longitudinal direction.

Growth modelling theory suggests that growth increments for plots with higher upper stem diameters should be enhanced. This follows from the fact that most univariate growth models can be decomposed multiplicatively with the structure in (2), which indicates that the *increment* will be proportional to the size, at any specified time. Consequently, it could be anticipated that greater growth increments would arise from plots exhibiting higher upper stem diameters.

$$\frac{d\,\mathrm{y}}{dt} = \mathrm{f}(t)\,\mathrm{y} \tag{2}$$

Where y is some measure of size and f(t) is a declining, or an eventually declining, function of time, so as to provide a declining relative growth rate (y'/y).

Models that can be classified in this way include Bertalanffy-Richards, Gompertz, Levakovic I, Levakovic III, Korf and Sloboda (see Table 1, Zeide 1993).

Conclusion

In assessing Coillte's database for yield modelling purposes three forms of sampling bias were identified. The first, through graphical analysis, indicates that Coillte's research data for Sitka spruce contains a sampling bias that omits lower site index material. The second, identified through the analysis of volume equation predictions, is associated with volume sample tree selection. The third is experiment blocking, which reduces randomisation at the plot level, increases cross-correlation between blocked plots, leads to the croding of statistical independence between plots and adversely affects parameter estimation in yield modelling equations.

In the context of fitting growth models the data omission issue influences all types of equations in any growth modelling system. The volume sample tree bias impacts on only the volume related components in a growth modelling system – these are the volume and assortment equations. The lack of randomisation at plot level typically impacts on all types of equation within any growth modelling system. In the context of analysing the established experiments as experiment designs, only the volume sample tree bias is of concern. The data omission and randomisation issue only arise once yield modelling is contemplated and data aggregation ensues. Clearly, the aggregation of data across repeated measures experiments has led to unanticipated consequences that have impacted negatively on the data requirements for yield modelling.

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The impact of calibration on the accuracy of harvester measurement of total harvest volume and assortment volume for Sitka spruce clearfells in Ireland

Tadhg Dooley[a], Traolach Layton[b] and Maarten Nieuwenhuis[c]

Abstract

Almost all timber in Ireland is felled using harvesters; the objective of the work reported here was to assess the impact of calibration on the accuracy of harvester wood volume measurement systems. The harvester used was a Timberjack 1270D with a 762C harvester head and a Timbermatic 300 control and measurement system. Harvester measurement was compared to weighbridge measurement (weight was converted into volume using volume-weight conversion factors) and to log volume, measured using standard calliper-and-tape log measurement.

The first part of the study dealt with the accuracy of the harvester system in measuring total and assortment volumes for whole stands, when compared to weighbridge results. Regular calibration resulted in a significant improvement in accuracy, reducing differences between the two estimates, from 12% to around 6%. However, this compares with accuracy levels of ± 2% of total site volume, which have been achieved in Finland on an annual basis.

The second part of the work comprised a more detailed analysis of the accuracy of the harvester system in measuring assortment volumes. Length measurement of four assortment categories was accurate after calibration, while the volume measurement was satisfactory for 5.50, 4.90 and 3.10 m lengths, but not for the 2.90 m category. Statistically significant differences in volume estimation were found for three assortment categories (4.90, 3.10 and 2.90 m). However, the differences between the harvester head and calliper-and-tape values were small (less than 30 mm and 0.007 m^3 in all cases), so the operational significance of these findings might be limited.

Keywords: Harvester, calibration, measurement accuracy, assortments.

Introduction

Almost all roundwood in Ireland is felled using mechanical harvesting systems. Modern harvesters come equipped with computerised measurement systems, which measure the stem during delimbing. Every time the stem is cross-cut, the machine measures the length assortment and the volume of the log (Rieppo 1993). If properly managed and maintained, these systems provide an accurate and cost-effective method of log measurement. They can provide precise results when installed, programmed and calibrated correctly. Accuracy levels of ± 2% of real volume have been achieved in Finland on an annual basis (Gingras 1995). There the measurements are used as a basis for optimising machine yield and assortment mix, payment of

[a] Forestry Services Limited, Dumdum, Co Tipperary, Ireland.

[b] Palfab Ltd.., Lissarda, Co Cork, Ireland.

[c] UCD School of Biology and Environmental Science, University College Dublin, Ireland (corresponding author: maarten.nieuwenhuis@ucd.ie).

contractors, payment of timber growers and the monitoring of operators (PTR 2000a). The data are also used in the mill to plan operations and select sawing patterns.

There are an estimated 64 harvesters and 144 forwarders operating in Ireland (Carlin 2005). About 50 harvesters have modern on-board computer systems (Fenton 2005).

The work reported here is part of a larger research project on sawmill production chain optimisation.

Background

Volume is one of the key measurements used to determine wood fibre quantity for stand production estimates, harvesting and timber sales. On the other hand weighbridge weight is used by virtually all boardmills and sawmills (Donnellan 2005) to estimate intake and for log stock control. Volume is obtained by applying a volume/weight ratio (Marshall and Murphy 2003), calculated by dividing the volume of a set number of sample logs by their weight. Purchases are paid for in euro per cubic metre overbark. When the logs from a specific sale arrive at the mill and are measured on the weighbridge, it is the first time in the sales process that the purchaser gets an accurate estimate of the actual total volume harvested and the distribution of this volume over the assortments.

On the other hand, almost all harvesting in developed countries is now mechanised, with single-grip harvesters predominant. All modern single-grip harvesters come equipped with computerised measuring systems. These measure the tree during delimbing; as it is fed through the harvesting head, a wheel measures the stem or log length and the delimbing knives or feed rollers measure the stem diameter at the same points. The log length and the diameter can be monitored using an in-cab display during operations. At every cross-cut the length assortment and volume of the log are recorded. Volume is measured using either sectional length and diameter readings or by using a single length and a top or mid diameter reading (Rieppo 1993).

A study carried out by Sondell et al. (2002) in Sweden on five harvesters and their computer systems, found that length and diameter sensing did not perform well, but that regular calibration of the measuring systems improved their performance.

Calibration involves checking, and if necessary correcting, harvester measurement by first measuring the volume of a log with the harvester and then using a tape and callipers. Provided measurement systems are set-up and calibrated according to design specifications, harvesters can provide accurate volume estimates. Requirements in Finland stipulate that harvester volume estimates must be ± 4% of the true stand volume. Accuracy levels of ± 2% of true stand volume have been obtained in practice (Gingras 1995). Studies on harvesting heads by the Forestry Commission in Britain reported similar accuracy levels to those recorded in Scandinavia (Forestry Commission 1995). In Ireland, a study carried out by PTR Ltd. in 2001 found volume accuracy levels of 6.7% for a clearfell site and 5.3% for a thinning site (PTR 2001a).

The aim of the research reported here was to further assess the accuracy of harvester head measurement systems under Irish forest conditions, focusing on the impact of calibration on measurement accuracy (Dooley 2005, Nieuwenhuis and Dooley, 2006). In order to achieve this aim, two studies were carried out.

First, an analysis was carried out of the accuracy of the harvester measurement system when dealing with the total harvest and assortment volumes from stands. Second, a detailed analysis of the accuracy of the calibrated harvester measurement system for different assortments was performed.

Materials and methods

Investigation sites

Harvest volumes and length assortment data were collected in five Sitka spruce (*Picea sitchensis* (Bong.) Carr.) stands, three in Co Cork and two in Co Limerick (Table 1), using a Timberjack 1270D with a 762C harvesting head and the Timbermatic 300 harvesting measuring and control system. Calibration checks and corrections were carried out at least twice at each of sites 2, 3, 4 and 5.

Measurement devices

Four measuring devices were used to calculate log length and volume:

1. the Pomo calliper,
2. loggers tape,
3. weighbridge measuring system and
4. the Timberjack On-Board-Computer-System (OBCS).

Calliper and tape diameter and length estimates were used to calibrate the harvester head. The calliper, loggers tape and the weighbridge measuring system were used to evaluate the accuracy of the harvester OBCS. The weighbridge measuring systems in the Palfab sawmill and the other mills to which the pallet and pulp wood was transported were used to assess the accuracy of the harvester OBCS

Table 1: Location and crop descriptions of the stands investigated.

Stand	*1*	*2*	*3*	*4*	*5*
County	*Limerick*	*Limerick*	*Cork*	*Cork*	*Cork*
Townland	*Park*	*Glennagowan*	*Cooragreenane*	*Coolen*	*Guagan Barra*
Forest	*Newcastlewest*	*Newcastlewest*	*Inchigeelagh*	*Inchigeelagh*	*Ballingeary*
Age yr	*44*	*41*	*43*	*43*	*42*
Thinned	*no*	*no*	*yes*	*yes*	*no*
Stems/ha	*1477*	*1408*	*846*	*626*	*1326*
Mean volume m	*0.41*	*0.40*	*0.50*	*0.64*	*0.47*
Mean dbh cm	*23*	*23*	*26*	*29*	*23*
Harvested area ha	*2.7*	*11.9*	*19.8*	*18.5*	*25.0*

for large volumes of timber, while the calliper and tape were used to assess the accuracy for individual logs.

The first part of the study dealt with total harvest and assortment volumes for four sites (1, 2, 3, and 4), comparing the harvester OBCS to the weighbridge measurement systems in the mills. It was carried out over a period of 14 months.

Weighbridge volumes were taken as the correct measurement and the harvester volumes were compared against these. Scheduled calibration checks (in addition to checks after repair work on the harvester head) were carried out once a month at every site, except for site 1 where no calibration checking was carried out; if necessary a full calibration of length and diameter was performed. The data from the harvester OBCS were collected on a daily basis via mobile internet connection to the sawmill. The weighbridge data were taken from the weighbridge computer systems when all the logs from the stand had arrived at the mills. The data were organised and analysed in each of four categories: total harvest volume, sawlog (5.50 and 4.90 m), boxwood (3.10 m) and pulpwood (2.90 m).

The second part of the study dealt with length and volume measurements of individual logs in four assortments (5.50, 4.90, 3.10 and 2.90 m) across three sites (3, 4 and 5). For this part of the study, the calliper-and-tape measurements were taken as the true or correct measurements, and the calibrated harvester OBCS measurements were compared against these. The data consisted of measurements on 375 logs in four assortments: 25 logs in the 5.50 m length assortment, 139 logs in the 4.90 m length assortment, 30 logs in the 3.10 m length assortment and 181 logs in the 2.90 m length assortment.

Results

Part 1 - Total harvest and assortment volumes

Site 1 (no calibration) produced a total true harvested volume of 2,144 m^3 as calculated at the weighbridge, while the harvester OBCS estimated a total volume of 2,416 m^3, resulting in a difference of 272 m^3 or 12.69% (Table 2). The proportions of total volume in each assortment, as determined from the harvester and weighbridge data, differed by between 1 and 5%. However, the actual assortment volume differences, expressed as a percentage of the 'true' weighbridge volumes, were much larger and varied between -6.2 and 21.0%. Site 2 (calibrated) produced a difference between the total true harvested volume and the harvester OBCS total volume of 399 m^3 or 6.69%. The proportions of total volume in each assortment differed by between 0.1 and 1.4%, while the actual assortment volume differences ranged between 4.8 and 25.2%. Site 3 (calibrated) produced a difference of -403 m^3 (–5.52%) between the weighbridge volume and the harvester OBCS volume (Table 4). The proportions varied by between 0.2 and 1.6%, while the actual assortment volume differences ranged between -11.5 and 18.9%. Finally, site 4 (calibrated) produced a difference of -300 m^3 (–5.18%) in total volume, while the assortment proportions differed by between 0.3 and 2.3% (Table 5). The actual assortment volume differences ranged between -7.8 and 11.3%.

Table 2: Comparison of weighbridge and harvester volumes for site 1.

Assortment	*Harvester volumes*		*Weighbridge volumes*		*Difference*	
	m^3	*% of total*	*m^3*	*% of total*	*m^3*	*%*
Sawlog (5.5, 4.9 m)	*1,397*	*57.83*	*1,155*	*53.87*	*242*	*20.98*
Boxwood (3.1 m)	*414*	*17.13*	*344*	*16.04*	*70*	*20.32*
Pulpwood (2.9 m)	*605*	*25.05*	*645*	*30.08*	*-40*	*-6.16*
Total	*2,416*	*100*	*2,144*	*100*	*272*	*12.69*

Table 3: Comparison of weighbridge and harvester volumes for site 2.

Assortment	*Harvester volumes*		*Weighbridge volumes*		*Difference*	
	m^3	*% of total*	*m^3*	*% of total*	*m^3*	*%*
Sawlog (5.5, 4.9 m)	*3,966*	*62.33*	*3,769*	*63.20*	*197*	*5.23*
Boxwood (3.1 m)	*599*	*9.42*	*479*	*8.03*	*120*	*25.16*
Pulpwood (2.9 m)	*1,798*	*28.25*	*1,716*	*28.77*	*82*	*4.77*
Total	*6,363*	*100*	*5,964*	*100*	*399*	*6.69*

Table 4: Comparison of weighbridge and harvester volumes for site 3.

Assortment	*Harvester volumes*		*Weighbridge volumes*		*Difference*	
	m^3	*% of total*	*m^3*	*% of total*	*m^3*	*%*
Sawlog (5.5, 4.9 m)	*4,951*	*71.76*	*5,257*	*71.99*	*-306*	*-5.82*
Boxwood (3.1 m)	*542*	*7.86*	*456*	*6.24*	*86*	*18.86*
Pulpwood (2.9 m)	*1,406*	*20.38*	*1,589*	*21.76*	*-183*	*-11.52*
Total	*6,899*	*100*	*7,302*	*100*	*-403*	*-5.52*

Table 5: Comparison of weighbridge and harvester volumes for site 4.

Assortment	*Harvester volumes*		*Weighbridge volumes*		*Difference*	
	m^3	*% of total*	*m^3*	*% of total*	*m^3*	*%*
Sawlog (5.5, 4.9 m)	*4,435*	*80.71*	*4,810*	*83.00*	*-375*	*-7.80*
Boxwood (3.1 m)	*351*	*6.39*	*348*	*6.01*	*3*	*0.86*
Pulpwood (2.9 m)	*709*	*12.90*	*637*	*10.99*	*72*	*11.30*
Total	*5,495*	*100*	*5,795*	*100*	*300*	*-5.18*

A graphical representation illustrates the effect calibration had on the harvester OBCS measurement accuracy of assortment and total harvest volume (Figure 1). The differences between the harvester pulpwood volumes and the weighbridge pulpwood volumes fluctuate between the four sites; however the differences between the harvester and weighbridge volumes for the sawlog and boxwood categories appear to be moving towards the 0% error line. For total volume an immediate improvement is apparent when the results for the first site (where the harvester measurement system was not calibrated) are compared with the next 3 sites (where calibration was carried out).

Part 2 – Length and volume of logs by assortment classes

Before presenting the results of the statistical analysis of length and volume differences, the range of volume differences between the harvester OBCS and the calliper-and-tape volume measurements of the sawlog/boxwood and pulpwood assortment classes are presented. These illustrate the different error distributions of these product categories. The analysis of the differences for the combined sawlog/boxwood class revealed that 54% of the differences were within the ± 4% range (Figure 2), with just over 90% of the differences within the ± 8% range. For the pulpwood class, the analysis revealed that 24% of the differences were within the ± 4% range (Figure 3). The largest proportion of differences (over 19%) fell in the 6-8% range. The difference in the error distribution of the two product classes is very evident, showing a normal distribution pattern for the sawlog/boxwood class and a uniform distribution for the pulpwood class.

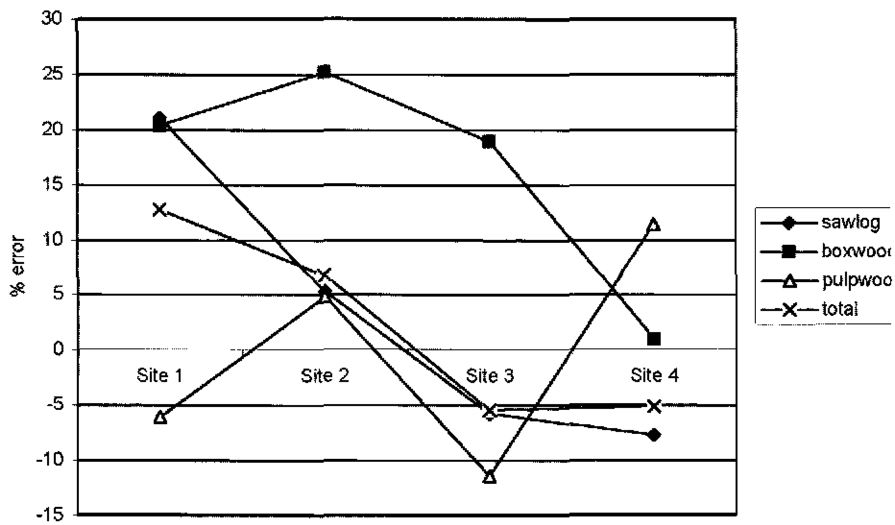

Figure 1: Percent error in the measurement of assortment volumes and total harvest volume for the four sites. No calibration took place at site 1, whereas regular calibration was carried out at sites 2, 3 and 4.

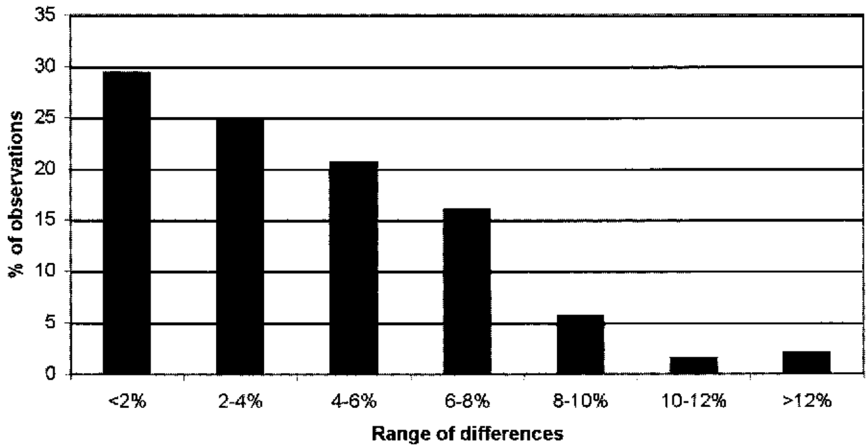

Figure 2: Frequency distribution (in %) of the range of differences in sawlog/boxwood volume measurements, between the harvester OBCS and the calliper-and-tape system.

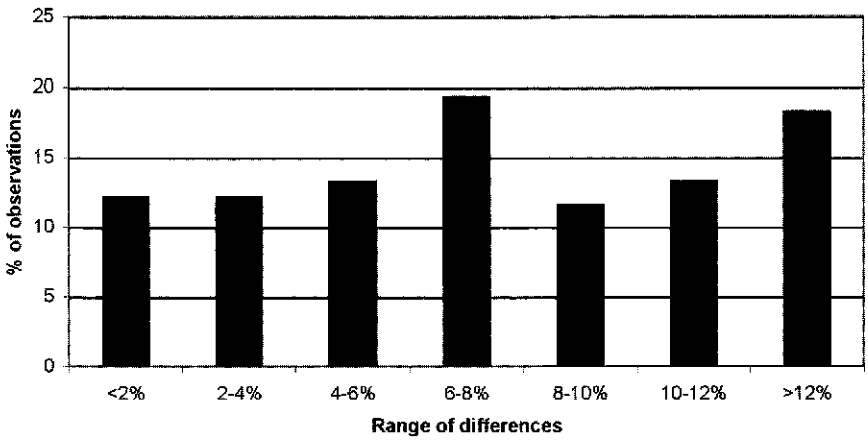

Figure 3: Frequency distribution (in %) of the range of differences in pulpwood volume measurements, between the harvester OBCS and the calliper-and-tape system.

Analysis of assortment length and volume differences

For all four assortments, the mean length measurements by the harvester OBCS were greater than the corresponding tape measurement means. Differences between mean tape and harvester length measurements were 0.02 m or less for the 4.90, 3.10, and 2.90 m assortment classes, with a 0.13 m difference for the 5.50 m assortment class. The variances associated with all means were very small, except for the tape measurement of the 5.50 m assortment. The low mean value and the large variation associated with these tape measurements were caused by a number of logs with actual (i.e. tape) lengths more than 20% below the target value of 5.50 m. A statistical analysis was carried out on the (normally distributed) length differences for the three longest assortment classes. A summary of the results is presented in Table 6. There was no significant difference in length measurements for the 5.50 m assortment class, while for the 4.90 and 3.10 m classes significant differences were found.

The mean volume measurements by the calliper-and-tape system were greater than the corresponding harvester OBCS measurement means for all four assortments. Differences between mean calliper-and-tape and harvester volume measurements were 0.007 m^3 or less for all assortments. The variances associated with all means were very small, except for the variances of the mean calliper-and-tape and harvester OBCS measurements at the 5.50 m assortment class. A statistical analysis was carried out on the volume differences for the three longest assortment classes and a summary of the results is presented in Table 7. There was no significant difference between the volume measurements for the 5.50 m assortment class, while for the 4.90 and 3.10 m classes significant differences were found.

Table 6: Statistical comparisons of length measurements for the sawlog and boxwood assortments.

Length	*Sample size*	*Harvester*		*Tape*		*t critical*	*t*
		Mean	*Variance*	*Mean*	*Variance*		
m		*m*					
5.50	*25*	*5.52*	*0.00020*	*5.39*	*0.12033*	*2.06390*	*1.94456*
4.90	*139*	*4.93*	*0.00020*	*4.91*	*0.00365*	*1.97731*	*2.36213**
3.10	*30*	*3.10*	*0.00004*	*3.09*	*0.00057*	*2.04523*	*2.64149**

**significant at the 95% confidence level*

Table 7: Statistical comparisons of volume measurements for the sawlog and boxwood assortments.

Length	*Sample size*	*Harvester*		*Tape*		*t critical*	*t*
		Mean	*Variance*	*Mean*	*Variance*		
m		*m*					
5.50	*25*	*0.373*	*0.0285*	*0.380*	*0.0296*	*2.06390*	*0.96935*
4.90	*139*	*0.217*	*0.0088*	*0.224*	*0.0098*	*1.97731*	*6.10368**
3.10	*30*	*0.077*	*0.0003*	*0.079*	*0.0003*	*2.04523*	*3.25579**

**significant at 95% confidence level*

Discussion

Part 1 - Total harvest and assortment volumes

The purpose of the first part of this study was to investigate the accuracy of the harvester OBCS measurement system compared to the weighbridge measurement system when dealing with total harvest and assortment volumes. The weighbridge measurement system is the predominant method of calculating stand volumes in Ireland (Donnellan 2005); therefore it was decided to evaluate the accuracy of the harvester OBCS measurement system against the weighbridge system. The weighbridge results for the sawlog and boxwood assortment categories are based on sale proposal specific weight/volume conversion factors and, as a result, should be very accurate. It is not certain if this was the case for the pulpwood results.

It was found that the accuracy of the harvester improved greatly after calibration. From a 12.71% difference between the harvester volume and the weighbridge volume at the first site (where no calibration was carried out) the accuracy improved to a 6.69% difference at the second site, and differences of –5.52% and –5.18%, respectively, between the harvester and weighbridge volumes at sites 3 and 4. These total volume differences of around ± 5% were very similar to results of a study carryout by PTR in 2001 where differences between the harvester and weighbridge volumes of 6.7% for a clearfell site and 5.3% for a thinning site were recorded (PTR 2001a). However, none of these harvester volume estimates are as accurate as those regularly achieved in Finland (± 2%) for total site volumes, which are used for contract purposes (Gingras 1995). A possible explanation for this high level of accuracy is that stems tend to be cleaner, with less and smaller branches, making it easier for the harvester head to delimb the stem, causing less measurement errors. The time of year during which harvesting takes place and its effect on the cohesion between bark and the underlying wood is another factor that may have an impact on length measurement accuracy in particular. If bark gets detached from the wood, the harvesting head wheel that is used for length measurement will measure the length of bark going through the harvesting head, not the length of the log. During the winter period in Finland bark is strongly attached, facilitating accurate length measurement. In addition, in Finland harvester measurement for timber sale purposes has been used for several years, while the studies reported here are among the first carried out in Ireland, reflecting the recent introduction and application of this technology in Irish forest operations.

The proportions of total volume in each of the harvester OBCS measured assortments compared to each of the weighbridge measured assortments were very similar, especially for the three sites where the harvester was calibrated. No difference between harvester versus weighbridge assortment proportions was greater than 2.3%. This is an important finding, as the processing industry needs to know the proportion of each assortment cut, allowing for production planning based on production data, customer orders and yard inventories (Nieuwenhuis 2002, Nieuwenhuis et al. 1999).

Even though the differences between the actual harvester and weighbridge assortment volumes were greatest at the site that was not calibrated (Site 1), large differences were also found between the harvester and weighbridge assortment volumes for the calibrated sites: sawlog volume estimates differed by between -7.80% and 20.98%; boxwood differed by between 0.86% and 25.16%; and pulpwood by between -11.52% and 11.30%. A reason for these differences could be that the calibration of the harvester was not carried out evenly for the full range of diameters encountered in each stand, e.g. volumes at small diameters were overestimated and volumes at large diameters under estimated, or vice versa. A study carried out by Sondell et al. (2002) showed that such errors can occur as a result of this type of inadequate calibration, even when the total volume estimate might be accurate. In addition, not all logs that have been measured by the harvester OBCS measurement system may have reached the mill. The data collected during the study did not include information on harvested timber left on site. A study by PTR on harvest volume residue found that up to 2.36% of the total volume can be left on site, while the loss of bark can affect total volume by an additional 2% (PTR 2001b).

Part 2 – Length and volume of logs by assortment classes

The purpose of the second part of the study was to investigate the accuracy of the measurements by the harvester OBCS for different assortment categories. It was found that the length category with the least accurate harvester length measurements was the 5.50 m category, with only 76% of the logs within the ± 0.05 m range. This maybe is not surprising, as even a small error in measurement per unit length can become substantial as a result of the long length of the 5.50 m category. The length as determined by the harvester was within ± 0.05 m of the true length for over 90% of the logs in each of the other three assortments (4.90 m category 92% of logs, 3.10 m category 96% of logs, the 2.90 m category, 91% logs). These three assortment categories meet the standard target in Sweden of 90% of the logs falling within 5 cm of the specified assortment length (Sondell et al. 2002).

In the analysis of volume accuracy, the proportion of logs within the ± 4% range was the critical factor. Requirements in Finland stipulate that volume estimates must be within ± 4% of the true volume (PTR 1997). It was found that the volume category with the least accurate harvester OBCS volume measurements was the 2.90 m category with only 24% of the logs within the ± 4% range. A reason for this low accuracy level could be that this length assortment is predominately cut from the top part of the stem which has the most branches and can be extremely rough (Joyce and OCarroll 2002). The volume accuracy of the sawlog/boxwood category, as determined by the harvester volume measurements, achieved 54% of the logs within ± 4% of the calliper-and-tape measurements. When the range is extended to ± 8%, almost 90% of the logs cut by the harvester in the sawlog/boxwood categories were within this wider range. This range is of interest because it is more representative of the level of harvester volume measurement accuracy that is being achieved in Irish forests (PTR 2000a). This sawlog/boxwood result was satisfactory but can probably be further improved by more regular calibration (PTR 2000b). However, for the logs cut by the harvester in the 2.90 m assortment, less than 60% are within the ± 8% range. It is not clear if more calibration will improve this result, as the roughness of the higher portion of the stems might make measurements with the current technology inherently unreliable and inaccurate.

In the comparisons of length, it was found that for all four assortments the mean length measurements by the harvester were greater than the corresponding tape measurement means. In contrast, the mean volume measurements by the calliper-and-tape method were greater than the corresponding harvester measurement means for all four assortments. The only logical explanation for these contradictory results is that the diameter measurements by the harvester produced smaller values than the calliper measurements. As it was not possible to record the individual harvester diameter measurement values used in the volume calculations, it was not feasible to check this hypothesis. When the differences between the harvester and calliper-and-tape length and volume measurements for the three sawlog and boxwood assortment categories were statistically analysed, the lengths and volumes differences for two categories were found to be significant (i.e. 4.90 and 3.10 m). However, the actual differences between the harvester and calliper-and-tape means for these assortment categories were extremely small (less than 3 cm and 0.007 m^3 all cases). From an operational perspective, these statistically significant but small differences may not have an important impact, and may indicate that the measurement system of the harvester was performing consistently and accurately.

Conclusions

Regular calibration improved the measurement accuracy of the harvester measurement system for the total harvest and assortment volumes on the four sites. However, even with calibration, several large differences were found between site assortment volumes as obtained at the weighbridge and as measured by the OBCS. A more detailed log-by-log analysis showed that length estimates obtained by the harvester measurement system were compatible with the results obtained with the tape measurement system for each of the four assortment categories. Volume estimates obtained by the harvester measurement system for the sawlog/boxwood category were relatively accurate; however volume estimates for the pulpwood category were unacceptable. If harvester measurement systems are to be used successfully, a major training initiative will be required to give contractors a proper appreciation of the importance of frequent and regular checking and calibration procedures.

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Forest Perspectives

Saint Patrick's Forest

Niall OCarroll[a]

Abstract
A review of surviving records and of modern commentaries indicates that Saint Patrick's Irish captivity was spent at or near a forest in Co Mayo, and not on Slemish in Co Antrim.

Keywords: Saint Patrick, captivity, Wood of Foclut, Ireland.

The basis
Experts agree that only two of the writings popularly ascribed to Patrick are authentic. Those are the *Confession*, which we deal with here, and the *Letter to Coroticus*, which does not concern us in this context (Hanson 1983).

The question
In the Confession Patrick refers to a 'Wood of Foclut' (*Silva Vocluti* alternatively *silua Uocluti*[1], and other versions, all dealt with extensively by Bieler (1943)). That wood was apparently located in the west of Ireland. Since the word 'wood' carries an implication of man-made woodland, and since the Latin word *silva* is a fairly broad term and since there were no plantations in Ireland at the time in question, we may more reasonably refer to it as a 'forest'.

In his paper, *The Problem* of Silua Focluti, Ludwig Bieler (1943) lists 21 authors who have speculated on the location of the Wood of Foclut since 1905, (including, in 1937, Henry Morris, father of a former Chief Inspector of the Forest Service). He adds, by way of comment: *Passing over so much learned literature, the student cannot help feeling that most of the authors mentioned have been happier in their criticisms of their predecessors than in their original contributions.*

A modern tourism booklet confidently asserts, although without offering supporting evidence, that: *This area, Focluth, which today is now known as Foghill, lies approx. eight kilometres north of Killala and the wood, 'Silva Focluti' extended from there to Crosspatrick cemetery on the Ballina road: and beyond*! (author's exclamation mark), (Dunford 2004).

The life
Reading some of the more scholarly writings about Patrick one becomes aware that much less is known for certain about him than many of us may have been given to

[a] Ballynakillew, Ballinrobe, Co Mayo, Ireland (nakillew@eircom.net).

[1] In Latin writing u and v tended to be used interchangeably.

understand in earlier years. It appears that most of the Patrician stories and traditions collected by for example Joyce (1913) are fictitious or apocryphal. A high proportion of them are derived from the so-called *Tri-Partite Life*, (the *Vita Tripartita*) composed between 859 and 901 and described by Hanson (1983) as a compilation ... *in which folklore and pious imagination have run riot; among other embellishments of the earlier story, this brings Patrick to visit Rome in the time of Pope Celestine, study there under Germanus, to spend a further period under Germanus at Auxerre, and, to finish things off properly, to live for a period as a monk at Tours under Martin (ob 397)*! ... He rejects all that. (It is of course acknowledged that the ancillary details as recorded by Joyce are valid as an indication of social conditions in ancient Ireland.)

The outline of Patrick's career, not seriously disputed among modern scholars, is summarised by Hanson (19830 as follows: *He was born in Britain of British* [not English as the Angles had not yet arrived] *upper-class or aristocratic parents. When he was nearly sixteen he was captured by Irish pirates*[2] *who carried him off to Ireland where he spent six years as a slave tending sheep. He then escaped from Ireland. Later he returned to Ireland as a bishop and spent the rest of his life evangelising there, and he died in Ireland.*

Documentary sources

As mentioned above, the *Confession* is one of only two of Patrick's writings which are regarded by authorities as authentic. The relevant passage in the *Confession*, in Hanson's translation is

'And next a few years later I was in Britain among my parents who [had] received me for their son and earnestly requested me that I should now after all the troubles which I had experienced never leave them, and it was there that *I saw a vision of the night* a man coming apparently from Ireland whose name was Victoricus, with an unaccountable number of letters, and he gave me one of them and I read the heading of the letter which ran, "The Cry of the Irish," and while I was reading aloud the heading of the letter I was imagining that at that very moment I heard the voice of those who were by the Wood of Voclut which is near the western sea, and this is what they cried, *as with one voice*, "Holy boy, we are asking you to come and walk among us again," and *I was struck deeply to the heart* and I was not able to read any further and at that I woke up. God be thanked that after several years the Lord granted to them according to their cry.' (Translator's italics indicate biblical quotations.)

In his comment on the foregoing passage Hanson writes *It is impossible to avoid the conclusion that the 'wood of Voclut which is by the western sea' was situated by the Atlantic on the west coast of Ireland. Patrick was in Ireland when he wrote these words; the only sea to the west of him was the Atlantic. To imagine that he could mean the Irish Sea between Britain and Ireland is absurd. It is equally far-fetched to*

[2] Joyce (1920) believes that this raid was 'probably' led by Niall of the Nine Hostages, although O'Rahilly (1942) suggests the involvement of Nath Í, king of Connaught, lending further credibility to the Mayo location of Patrick's captivity.

think that 'the children of the Wood of Voclut' were not the people among whom Patrick had spent the years of captivity, especially as in the dream they call him to come and live among them 'again'. This means that the place where he was kept a slave for six years was on the west coast of Ireland, and the necessity which faced him when he escaped of travelling two hundred miles[3] *fits in well with this. When therefore Tirechán tells us that the Wood of Voclut was in the district of Tirawley (near the small town of Killala on the sea-coast of Mayo not far from the border between Mayo and Sligo), we can well believe him. Tirechán himself came from that area, and place names survive unchanged much longer than any other form of tradition. These conclusions are, of course, fatal to the later story that Patrick spent his captivity on Mount Slemish in Co. Antrim.*

This was also the conclusion of Bieler (1949) who regarded any attempt to locate the Wood of Foclut in the north-east as ... *blocked – for good, as it seems to me – by O'Rahilly.*

In that later and more general treatment[4] which, he implies, is less opinionated, Bieler (1949) suggests that the Wood of Foclut of Patrick's dream may be no more than a place he had heard about during his captivity. To the present writer this is considerably less convincing than to conclude that the location of his dream was a place where Patrick had lived as a youth.

It is remarkable that, as pointed out by O'Rahilly in his 1942 publication, the Wood of Voclut is one of only two place names mentioned by Patrick in his *Confession*; the other, his home village in Britain, has never been identified.

Localities

John O'Donovan of the Ordnance Survey, writing to his headquarters from Ballina on 12 May 1838 asks to be sent ...*the references in Tirechan* [to] *the Tripartite* [Life] *and Usher*[5]*, to the Wood of Fochlut (Caill Fochlut) where St. Patrick in a vision saw the Irish with outstretched hands, beseeching him to come to their assistance. Usher states that it was in the Barony of Tirawley in the Co. of Mayo, and it is added in other authorities that Patrick afterwards built a church there...* On 24 May he writes that *This Barony of Tirawley, seems to be as large as the Co of Louth. It will take more time to traverse than I had anticipated* (O'Donovan 1838). (As well as Killala, Tirawley includes the towns of Ballina and Crossmolina.) On 30 May T. O'Connor, a colleague, writes from Killala *Coille Fochladh is a district of which I have not yet ascertained the extent.* It appears that no trace of St. Patrick's presence was found at that time. That is not surprising in view of Hanson's comments on the veracity of the legends.

[3] ducenta milia passus; literally 200 x 1000 Roman paces = 184 statute miles or 296 km.

[4] It may be of interest that this book carries a NIHIL OBSTAT from the diocesan censor and an IMPRIMATUR signed by Archbishop John Charles McQuaid.

[5] James Us[s]her (1581-1656) Archbishop of Armagh 1594. Condemned the use of Irish in the Church of Ireland. He concluded that the world had been created in 4004 BC.

Bieler (1943) repeats Tirechán's identification of *...the wood of Fochloth (Fochlad)...* in Connacht, a place-name commonly believed to survive in modern Foghill (Fochoill) near Killala, Tirawley, Co Mayo. Joyce (1869-1913) derives Foghill, in Mayo, from the Irish *Fo-choill*, underwood, suggesting a woodland connection. According to modern Ordnance Survey maps Foghill is located about 6 km (4 miles) north-north-west of Killala. However, O'Rahilly (1942) dismisses this identification as having ... *no basis; the resemblance between the names is deceptive* ... On etymological and linguistic evidence he concludes that the name of the wood would be better rendered as *...the Sheltering Wood...* He suggests that the Wood of Foclut lay to the west of the present Crosspatrick, which is two kilometres ($^1/_4$ mile) south-west of Killala, and mentions the townlands of Tawnaghmore (Lower and Upper) and the adjoining Farragh.

Patrick's account has the Latin clause: *ut etiam in siluis et in monte manebam*, which Hanson translates as 'even when I was staying out in the woods or on the mountain', and regards this as uninformative as to location since ... *almost any part of the coast of Ireland exhibits those features, or did in Patrick's day* ... If we advert specifically to the word 'mountain' then the high point closest to the group of townlands mentioned is 77 m (253 feet) south of Tawnaghmore. Next there is a peak of 237 m (777 feet) about 10 km (6 miles) north-west of Killala. The summit of Nephin mountain at 808 m (2646 feet) is about 24 km (15 miles) south-west of Killala.

According to Joyce (1869-1913) Tawnaghmore means 'great field'. He explains 'Tamhnach' as signifying ... *a green field which produces fresh sweet grass* ... Ó Dónaill (1977) defines it as ... *grassy upland; arable place in mountain* ... These definitions suggest a non-forest terrain, possibly sheep pasture. Joyce explains 'Farragh' as from the Irish 'Farrach' or 'Forrach': a meeting-place. Ó Dónaill has only 'forrach', with, among several meanings 'area, tract, of land; (meeting-) place.' Joyce identifies 'Tir-Amhalgaidh i.e. Awley's district, now the barony of Tirawley', and quotes the Tripartite Life as claiming that Patrick once preached there at *Forragh-mac-nAmhalgaidh* (Forragh-mac-nawley) i.e. the assembly place of Amhalgaidh's clan, baptized the seven sons of Amhalgaidh, and twelve thousand others. In this connection we may bear in mind Hanson's comments, above, on the Tripartite Life. Joyce tells us that Tirechán latinises *Forrach as forrgea*. Joyce further quotes O'Donovan to the effect that the name survives as the townland name of Farragh, 'about a mile and a half south-west from Killala'. In fact, O'Donovan appears to go no further than to identify the territory *Caille anciently Caille Fochlut* as one of the seven territories of 'Tir-Awley'. Knox (1908) presents a map of *Connaught West of the Shannon in the 5th Century* showing 'CAIL FOCLADH' bounded approximately by the Cloonaghmore and Ballinglen rivers and the sea.

No large-scale soil maps of this region have been published. The General Soil Map of Ireland (Gardiner and Radford 1980) characterizes the local soil association as 'rather complex', consisting of 50 percent Degraded Grey Brown Podzolic associated with 15 per cent Brown earths, 15 per cent Peats, 10 per cent Gleys, and 10 per cent Podzols. Its use range is described as 'mainly grassland'.

A soil in its location is not a static system. It has evolved, over centuries and millennia, under the influences of leaching and eluviation, altering its chemical and physical characteristics, usually for the worse. The soils in this general area, derived from calcareous materials, would have been considered moderately desirable for agriculture, and would therefore have become deforested in early historical time. It is known that farming was practised some thousands of years BC at the so-called *Céide Fields* about 18 km (11 miles) north-west of Killala, on the mineral soils beneath the present blanket bog.

There can be no doubt that in the fifth century considerable areas of forest existed here but it could be delusive to speculate on their species composition: Mitchell (1986) states that *Scots pine ... probably died out in Ireland in the early centuries of the Christian era*, which seems to admit the possibility that it may have been present here, while oak and ash remained widespread.

No sizeable areas of woodland were recorded in the first mapping of this part of Co Mayo carried out in the 1830s by the Ordnance Survey and published at the scale of 1:10560 (6 inches to one mile).

These areas now present a bleak, generally treeless and rather exposed landscape of permanent grassland. Rushes (*Juncus* spp) are more prominent around Farragh, as might be expected from the presence of gleys within the association. According to Ordnance Survey maps ancient monuments: ringforts, standing stones, megalithic tombs, ancient cooking places (*fulachtaí fia*) etc., are scattered about the area indicating many centuries of human presence.

Ó Muraíle (1982) is cautious. He writes that Tirechán, a Mayo bishop, writing about 670, ... *was one of the two main progenitors of what was to become 'the Saint Patrick legend'*. His account ... *is essentially propaganda on behalf of the church of Armagh, [but] may be of little value in relation to the life and works of the historical Patrick.*

Simms (1991), in a small book which is apparently aimed primarily at a youthful readership, emphasizes that ... the *Woods of Focluth by the western sea* is the only place in Ireland mentioned by Patrick, and he accepts its location in Mayo. But he repeats and apparently accepts the later legends associating Patrick with the north-east, in particular Antrim and Armagh. George Otto Simms was Archbishop of Armagh and Primate of all Ireland (Church of Ireland) 1969-1980.

Outcome

An ineluctable conclusion is that Patrick's period of captivity was in or near a forest in north Co Mayo, and not in Co Antrim. In this connection Hanson anticipates Ó Muraíle in implying that the development of the Armagh legend in the seventh century was to provide propaganda in support of Armagh's claim to have jurisdiction over the whole Irish church.

Saint Patrick's oak

Incidental to all of this it may be interesting to note that an oak tree was ceremonially planted by the President of the Society of Irish Foresters, O.V. Mooney in the course of a Society Study Tour in the Black Forest. A photograph of that tree, taken in 1957, with a plaque which reads, in translation, *St Patrick's oak planted on 1st June, 1956, by members of the Society of Irish Foresters on the occasion of their visit to Zwingenberg,* appeared in *Irish Forestry,* Vol. 14 (2), Winter 1957, page 76. It is understood that a recent effort to locate that tree proved fruitless.

Acknowledgements

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Since the present writer is neither a historian nor a classical scholar, having but small Latin and no Greek, it has been necessary to rely almost exclusively on secondary sources. The following are the principal publications used.

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Notes on sources

Ludwig Bieler (1906-1981) was born in Vienna. After a varied career he occupied a specially established Chair in Palaeography and Late Latin in University College, Dublin, 1960-1976. He was regarded as one of the most internationally distinguished scholars to have been on the staff of the University. (Information by courtesy of Kate Manning Archivist, UCD.)

RPC Hanson (1916-1988) of English birth, was educated in Trinity College, Dublin, qualifying with 1st Honours in Classics and in Ancient History in 1938. He served as curate in some Irish parishes, including Banbridge, Co Down, before moving to academic posts in England. He was Professor of Historical and Contemporary

Theology in the University of Manchester, 1973-82. Author of many books on religious and ecclesiastical matters.

Patrick Weston Joyce (1827-1914), historian and music collector, author of many scholarly volumes on history, place names and music.

G.F. (Frank) Mitchell (1912-1997). Graduated from Trinity College, Dublin and joined in the pioneering studies of Irish bogs by means of pollen analysis. Lectured in Irish archaeology, and, in 1965, appointed to a specially created Chair of Quaternary Studies.

John O'Donovan (1809-1881). Edited and translated in seven volumes the Annals of the Four Masters. Employed by the Ordnance Survey, his letters from all parts of the country were issued in fifty volumes in 1927.

T.F. O'Rahilly (1883-1953), was a leading authority on Irish dialects and on medieval and modern Irish. Director, School of Celtic Studies, Dublin Institute of Advanced Studies.

G.O. Simms (1910-1991), Awarded Ph.D. for work on the Book of Kells. Archbishop of Armagh and Primate of All Ireland (Church of Ireland), 1969-1980. Noted for his ecumenical work.

Trees, Woods and Literature – 30

Early next morning, before the little girl had woken up, the tenant and her husband set off for the next village. There they'd be able to buy some white bread with his army ration-card.

They walked along hand in hand, without saying a word. They had to go one and a half kilometres through the forest, climb down the slope and then walk along the shore of the lake.

The snow here hadn't thawed. Its large, rough crystals were filled with the blue of the lake-water. But on the sunny side of the hill the snow was just beginning to melt. The ditch beside the path was full of gurgling water. The glitter of the snow, the water and the ice on the puddles was quite blinding. There was so much light, it was so intense, that they seemed almost to have to force their way through it. It disturbed them and got in their way; when they stepped on the thin film of ice over the puddles, it seemed to be light that was crunching under their feet, breaking up into thin, splinter-like rays. And it was light that was flowing down the path; where the path was blocked by stones, the light swelled up, foaming and gurgling. The spring sun seemed to be closer to the earth than ever. The air was cool and warm at the same time.

The officer felt as though his throat, which had been scorched by frost and vodka, which had been blackened by tobacco, dust, fumes and swear-words, had suddenly been rinsed clean by this blue light. They went into the forest, into the shade of the young pine trees. Here the snow hadn't melted at all. There were squirrels hard at work in the branches above; the icy surface of the snow was littered with gnawed fir-cones and flakes of wood.

The forest seemed silent. The many layers of branches kept off the light; instead of tinkling and gurgling, it was like a soft cloak swathed around the earth.

They walked on in silence. They were together – and that was enough to make everything round seem beautiful. And it was spring.

Still without saying anything, they came to stop. Two fat bullfinches were sitting on the branch of a fir tree. Their red breasts seemed like flowers that had suddenly blossomed on enchanted snow. The silence was very strange.

This silence contained the memory of last year's leaves and rains, of abandoned nests, of childhood, of the joyless labour of ants, of the treachery of foxes and kites, of the war of all against all, of good and evil born together in one heart and dying with this heart, of storms and thunderbolts that had set young hares and huge tree-trunks trembling. It was the past that slept under the snow, beneath this cool half-light – the joy of lovers' meetings, the hesitant chatter of April birds, people's first meetings with neighbours who had seemed strange at first and then became part of their lives.

Everyone was asleep – the strong and the weak, the brave and the timid, the happy and the unhappy. This was a last parting, in an empty and abandoned house, with the dead who had now left it for ever.

Somehow you could sense spring more vividly in this cool forest than on the sunlit plain. And there was a deeper sadness in this silence than in the silence of autumn. In it you could hear both a lament for the dead and the furious joy of life itself.

It was still cold and dark, but soon the doors and shutters would be flung open. Soon the house would be filled with the tears and laughter of children, with he hurried steps of a loved woman and the measured gait of the master of the house.

They stood there, holding their bags, in silence.

From the novel *Life and Fate* by Vasily Grossman (pp 869-871), The Harvill Press, London, 1995. Reproduced by permission of the publishers.

Life behind the Russian lines during the Second World War and the battle for Stalingrad form the main backdrop for *Life and Fate*. The extract forms the concluding passage of the book.

Life and Fate has an interesting history. When Grossman submitted the book for publication to the Soviet journal *Znamya* in 1960 it was passed to the Cultural Section of the Central Committee. A year later it was returned to the writer – with a note to say the novel was anti-Soviet. Shortly afterwards the KGB confiscated the manuscript from Grossman's home, as well as all other material associated with the book, even down to used carbon paper and typewriter ribbons. Grossman however wrote to the Politburo asking for his manuscript to be returned, only to be told that the book would not be published for another two hundred years. Despite many setbacks the manuscript did eventually gain publication, to great acclaim, in the early 1980s, with the first British edition published in 1985.

The book has been compared to *War and Peace*, no surprise given Grossman's great admiration for Tolstoy. In his war memoirs - *A Writer at War*[1] - he recounts persuading his companions to take a twenty kilometre detour to visit the Tolstoy estate, Yasnaya Polyana, while being hotly pursued by the advancing Wehrmacht. (The incident recalls to this writer other literary detours while in the company of senior forestry officials, not all in similar perilous circumstances, but undertaken with similar determination. Official travel claims were course adjusted to remove nugatory expenditure.)

Vasily Grossman was born in 1905 in the Ukrainian town of Berdichev. After an eventful childhood he enrolled in Moscow University in 1923 to study chemistry. Following graduation he worked as a mining engineer in his native Ukraine, but returned to Moscow shortly after his appointment, having been misdiagnosed as suffering from tuberculosis. There he began a successful writing career and he became a member of the Writers Union, a position of considerable privilege.

[1] **A Writer at War. Vasily Grossman with the Red Army 1941-1945**. 2006. Edited and translated by Anthony Beevor and Luba Vinogradova. Pimlico, London.

Immediately following the outbreak of war with Germany in 1941 Grossman sought to enlist in the Soviet army. Although he was initially turned down on physical grounds, his determination to contribute to the war effort resulted in him becoming a war reporter for the Red Army newspaper *Red Star*. His reputation grew throughout the conflict, and by its end in 1945 he was an acclaimed war hero.

After the war Grossman's fortunes fluctuated, but from 1960 onwards *Life and Fate*, its content, and his attempts to publish it, brought him into disfavour with the Soviet authorities. He died in 1964, without seeing his masterpiece published.

Grossman's descriptive and allegorical skills as a writer come to the fore in the extract. His choice of a forest scene, the description of the early morning thaw and the play of light, all chosen with deliberation, and at the end of the novel, serve to counterbalance the life and fate scenes played out in the preceding pages. The silence between the two persons, the wildlife in the forest, the stillness – are brilliantly staged to provide an extended reflection on life and fate, on the end of conflict, on spring and on new beginnings. Anyone who has walked through a forest on a sunlit morning in early spring can appreciate how acutely one can sometimes sense the awakening of nature, and of how well Grossman conveys this sense.

(Selection and note by *Lia Coille*)

Book reviews

Woodlands. Oliver Rackham. Collins. 609 pp. 172 illus., 26 tabs. £45 (sterling) hardcover (also available in paperback). ISBN 0-00-720243-1.

'I am not a forester' are Oliver Rackham's words on the second page of his Author's Forward to the book *Woodlands*. That is an item of information which any reader might deduce from even a casual perusal of the book. In fact his attitude to 'forestry', as it is usually understood by foresters, can be described as distinctly unsympathetic.

This book is volume 100 in the Collins New Naturalist Library begun in 1945. Many foresters will be familiar with H.L. Edlin's *Trees, Woods and Man* (1956), which was volume 32 in the series and some may have read W.H. Pearsall's excellent *Mountains and Moorlands* (Volume 11, 1950).

Rackham qualified as a botanist from the University of Cambridge in 1961 and has remained there in an academic capacity. He is highly regarded as an expert on the British countryside and its woodlands, and on other countries' ecology. That is in itself a worthwhile pursuit. The publisher's blurb declares that this book 'explains how trees and woods behave, for example how they coppice and pollard, how they are affected by storms and fire, the function of tree roots, the life and growth of trees and how and why they decay. Rackham reconstructs British woodland through the ages, from the evolution of wildwood, through man's effect on the landscape, modern forestry and its legacy, and recent conservation efforts and their effects.' Fair enough if you are of a purely naturalistic turn of mind, irrespective of practical utility. But his disparagement of 'forestry' betrays the botanist/ecologist/academic outlook in an extreme form. He appears not to accept that forestry is an activity whose primary purpose is to produce an industrial raw material, although almost in the same breath he complains of Japan, Britain and Ireland 'going through a phase of plundering other countries' wildwood'. He fails to mention that John Evelyn in his famous book *Sylva or a Discourse of Forest-Trees* (1664) recommends Ireland as 'better' for iron-smelting as that would help to conserve England's woodlands, at the expense of Ireland's.

He even writes disrespectfully about certain oak plantations from the 1830s, asserting that these 'monotonous, even-aged stands of rather poor-quality oak became somewhat of an embarrassment'. The question, an embarrassment to whom? Is left hanging in the air.

In a chapter on woodland history the years 1950-1975 are referred to as the locust years, a reference to the passage in the Old Testament Book of the Prophet Joel which, in the King James Version reads: 'And I will restore to you the years that the locust hath eaten, the cankerworm, and the caterpillar, and the palmerworm, my great army which I sent among you.' He develops this as follows: 'The chief agent of destruction was modern forestry: woods were felled and poisoned, and plantations made on the site. Usually the plantations were of conifers; foresters were obsessed with fast growth and had forgotten what woodland was for.' So that settles the

Forestry Commission! And the question 'what was woodland for?' also remains unanswered, unless we advert to the passage headed 'Replacing wild with planted oaks' where it is stated that 'Wild-type oaks are part of a wood's integrity, appearance and value as a habitat. It is part of the meaning of oak that oaks should not all be the same. It is irregularities that make oak such an excellent habitat for other wildlife.' That is not a view likely to be entertained by the managements of some of the famous oak forests of Germany and France.

Rackham is clearly not an enthusiast for economic calculations. He accuses W.E. Hiley, erroneously, of having depended solely on records from Indian plantations to illustrate the use of the Faustmann formula, which he does not identify by name, and gives an Irish source reference for this. In fact that Irish source has no detailed treatment of forest economics and does not mention either Hiley or Faustmann.

It may be a shooting-in-foot lapse when he describes conservation as having 'grown into a middle sized industry...with no well-defined enemy'.

Any forester reading this expensive book would need to maintain a critical attitude throughout.

Niall OCarroll

(Dr Niall OCarroll is a former Chief Inspector of the Forest Service and an author of a number of books on forestry in including *The Forests of Ireland,* published by the Society of Irish Foresters, and more recently *Forestry in Ireland – A Concise History*, published by COFORD.)

Potential Natural Vegetation of Ireland. J.R. Cross. Biology and Environment Proceedings of the Royal Irish Academy Vol.106B No.2. No price given.

Dr Cross introduces the publication by stating that Ireland is one of the few countries in Europe that does not have a detailed map of the natural vegetation of the entire land mass. While there have been numerous studies of Irish vegetation which have resulted in the production of maps of many different scales, including large-scale maps of specific vegetation types such as agricultural grasslands, peatlands and even detailed localised maps of specific areas, no attempts at an overall synthesis of the natural vegetation has been published to-date apart from that of Noirfalise[1] (1987).

The need for vegetation maps is nevertheless widely recognised among European botanists, and this has led to international collaboration and the production of a map of the natural vegetation of Europe at a scale of 1:2.5 m (Bohn[2] et al. 2000). Cross

[1] Noirfalise, A. 1987. *Map of the natural vegetation of the member countries of the European Community and the Council of Europe.* Office of the Official Publications of the European Community, Luxembourg.

[2] Bohn, U., Gollub, G. and Hettwer, C. 2000. *Map of the natural vegetation of Europe.* Federal Agency for Nature Conservation, Bonn-Bad Godesberg.

expands the scale of this map, with some revisions, and includes a description of the vegetation units, while retaining the classification system used in the latest map of the natural vegetation of Europe (Bohn[3] et al. 2003).

The concept of potential natural vegetation is briefly outlined and the paper highlights the factors affecting its development. These include climate, soil type, vegetation history, land use and other biotic factors. This is followed by a resume of the present day vegetation, with references for the main sources of data and a description of the methods used to compile the units and construct the map of the natural vegetation of Ireland. Twenty different vegetation units are described (which fit into six formation complexes), comprising nine forest units, five mire units, two heath units, two sand dune units and one salt marsh unit and one polder unit. The main text consists of details of vegetation habitat, land use and conservation status for each vegetation unit.

Minor vegetation types are also considered briefly, and the proceedings conclude by examining the general distribution and character of Irish potential natural vegetation and its relationship with the rest of Europe. Dr Cross states that while some work has been completed a great deal more work is required for the production of a more detailed map that would adequately depict the heterogeneity of Irish vegetation. He reminds the reader that interpretation of the map should therefore be undertaken with caution, bearing in mind that the vegetation units represent complexes in which only the principal vegetation type is depicted.

The potential vegetation in Ireland differs from that of Britain and nearby parts of the continent in three major respects. Firstly, the impoverished flora, and in particular the absence of certain important forest tree species, results in floristically less diverse forest communities. Secondly, the mild moist climate of Ireland results in the widespread occurrence of Atlantic and sub-Atlantic species, in particular bryophytes and lichens. Thirdly, the area of mitres in Ireland is greater than in any other European country at these latitudes (Ratcliffe and Oswald[4] 1988).

The diversity of the Irish landscape and vegetation is a product of natural variation in rock type, soil and climate overlain by millennia of human activity. This has resulted in a fine-grained mosaic of semi-natural and anthropogenic vegetation types. As presented, the map of the potential natural vegetation of Ireland clearly has limitations. However, when used in conjunction with the descriptions of vegetation units provided in this paper, it can provide an indicative guideline for land use and planning. The author points out that Bohn et al. (2000) have discussed the general use of such maps as follows:

- use as a baseline for a pan-European habitat and landscape classification, assessment and mapping system for nature conservation purposes,

[3] Bohn, U., Gollub, G., Hettwer, C., Neuhauslova, Z., Schluter, H. and Weber, H. 2003. *Map of the natural vegetation of Europe 1-3*. Bonn-Bad Godesberg. Federal Agency for Nature Conservation.

[4] Ratcliffe, D.A. and Oswald, P.H. 1988. *The Flow Country peatlands of Caithness and Sutherland*. Nature Conservancy Council, Peterborough.

- determination and evaluation of the degree of naturalness of the actual vegetation and landscape,
- establishment of representative national and international networks of protected areas,
- establishment of an international network for comparative observations of processes and changes in ecosystems, for example, for monitoring air pollution and climate change,
- for planning and restoration programmes, for example selection of appropriate species for afforestation.

The author highlights the uniqueness of the Irish flora arising from its geographical location and relative isolation, which has been the subject of considerable discussion in the past (Praeger[5] 1934, Webb[6] 1983). The map of potential natural vegetation indicates that this applies not only at a species level but also at a community level. Some communities for example, Atlantic raised bog and bryophyte- and lichen-rich sessile oak forests, have their European headquarters in Ireland while others, such as alder-oak-ash forests may be unique to Ireland. Dr Cross postulates that the production of a more detailed map will require considerable effort, even with modern methods of remote sensing, however he argues that natural vegetation is a basic resource of a country that should be incorporated more fully into land-use and planning policy, where the practical value of such a map and accompanying descriptions will be recognised. Finally, he concludes that this debate may eventually lead to the production of a more detailed and accurate map of Ireland's vegetation which would be comparable to those currently available in other countries.

One cannot but agree with Dr Cross's proposition that natural vegetation is a basic resource of a country that should be incorporated more fully into land use and planning policy. This is especially important in the development of a national forestry programme. The publication is timely and should provide a useful preliminary guide for ecologists and foresters, as it describes the vegetation units and complexes into which they fit. However, as highlighted by the author, a great deal more work is needed in this area to complete a comprehensive map of Irish vegetation.

John Fennessy

(John Fennessy is Research Programme Manager for Tree Improvement in COFORD. He is the Irish representative on the council of the British and Irish Hardwoods Improvement Programme (BIHIP) and chairs its Oak Group.)

[5] Praeger, R.L. 1934. *The botanist in Ireland.* Hodges Figgis, Dublin.

[6] Webb, D.A. 1983. The flora of Ireland in its European context. *Journal of life Sciences of the Royal Dublin Society* 4: 143-160.

Sixty-first Annual Study Tour New England 13-24 September 2004

Forty-one Society members assembled on 13 September 2004 at Dublin Airport to begin the 61st study tour to New England and the Society's second visit to the United States of America. The flight to Boston was via Philadelphia with US Airways. Professor Pete Hannah, Professor Emeritus, Silviculture, University of Vermont met and welcomed us at Logan Airport, Boston. Pete was the perfect host and guide for the ten days, and worked tirelessly and efficiently to look after the needs of the group. The Society is deeply indebted to him.

We drove west to our first night's accommodation at the Best Western Yankee Drummer Inn in Auburn, Massachusetts and were met by Kathleen Schomaker, Director of Alumni Affairs, Yale School of Forestry & Environmental Studies who had arranged the contacts for the trip.

Over the next ten days the group visited the states of Massachusetts, New Hampshire, Vermont and Maine. The forests of New England are mostly located on abandoned farmland, originally cleared of tree cover in the late 19th and early 20th centuries. The many abandoned railroads and lumberyards testify to the extent of previous harvesting activities.

One would expect the most heavily forested area in America to be the west coast states, but in fact the most forested state is Maine, with 90% forest cover, followed by New Hampshire (85%), and Massachusetts and Vermont (80%). The group learned a lot about the development of the industry but the one thing that defied everyone was the conversion of board feet to cubic metres! It appears like trying to add apples and pears.

John Mc Loughlin, Tour Convenor

Tuesday 14 September

We left the Best Western and headed for our first stop at Quabbin Reservoir Forest, owned by the Massachusetts Water Resources Authority, where we welcomed by Bruce Spence, the local forester. Located 100 km west of Boston, the reservoir supplies over 1,100 million litres of water per day to over 2.5 million people, as well as generating hydroelectricity.

The forest area covers some 30,000 ha, with the reservoir covering an additional 10,000 ha. Red pine (*Pinus resinosa*) is the main species, but it is planned to convert these areas to broadleaves (white-tailed deer are posing a problem for regeneration). Further north in New England, white pine (*Pinus strobus*) dominates; it is also the main commercial species – whereas red pine was planted more for soil conservation reasons.

While grey squirrels were numerous they were not causing damage to trees, and this appeared to be the case throughout.

The forest is FSC certified, with 20% of the area being retained for conservation A 100-year rotation is practised, with natural regeneration the preferred option on one third of the area. Clearfells generally vary in size from 20-25 ha, but some can be as small as 6 ha, while others can reach 40 ha. Red oak is the most valuable timber species, but most income derives from pine, as it is predominant species.

We departed Quabbin Reservoir Forest to arrive at Harvard Forest Museum, where we were welcomed by the Director, John O'Keefe. The museum was established to demonstrate the Harvard Forest approach to environmental science, in which a sound understanding of landscape history provides a basis for interpretation and conservation of nature. It was established in 1907, when the forest was established by Harvard University. This historical/ecological approach has proved applicable to modern environmental issues, as it becomes increasingly apparent that changes in nature can only be assessed through long term perspectives.

The museum comprises of a series of realistic looking miniature trees of various species, each species with its unique features, branching form and bark characteristics. It also includes woodland scenes with the appropriate grouping of vegetation, wildlife and landscape features, such as laneways, stone walls, and farmsteads.

After visiting the museum we travelled to Harvard Forest, and were welcomed by Matt Kielty, Professor of Silviculture, University of Massachusetts.

The forest comprising 1,200 ha is located just over 100 km west of Cambridge, Mass. A range of habitats, typical of those found throughout New England occur, including northern, transition and central forest types, hardwood swamp, conifer bog, forest plantation, as well as a 24 ha pond.

The great storm of 1938, which had wind speeds of up to 130 miles/hour recorded, blew down 70% of the pine. Most was unthinned white pine, growing on abandoned pasture land – a type of forest which is quite susceptible to windthrow. After the storm the wood was harvested, the slash was piled and burned, and no further intervention was made.

Appropriately, the first stop was at a 65-year-old stand that regenerated following the storm. It was comprised of oak, three birch species (black, paper and yellow), and red maple, plus a small number of white pine and hemlock. Paper birch and red oak dominated the overstorey until recently, but the birch is now dying back, having reached the end of its life span. Red oak is now the main species, with the larger trees having dbh's of 30-38 cm.

The second stop was at another mixed stand, located on a moist, finely textured soil, with a hard pan layer at about 60 cm. The history of the area is as follows:

1750	virgin forest cleared to create pasture
1843	pasture abandoned
1908	pine overstorey (age 65) removed after good pine seed fall; broadleaf understorey cut back
1912, 1916, 1919	broadleaves weeded by machete, mainly to free best pine seedlings, but also best hardwoods as well

1933	very few co-dominant pine, thinning to favour best red oak and paper birch
1940, 1947, 1968	thinning to favour best broadleaf crop trees.

By 2004, the largest red oak had a dbh of 55 cm, at 8 m spacing. Standing volume was about 220 m^3/ha.

The next stop was at an unmanaged natural stand, about 150 years old. It had never been cleared for pasture but instead was maintained as a woodlot during the period when agricultural land-use predominated. It was harvested in the mid 1800s, but some smaller hemlock were left uncut. These now form the largest trees, at 90 cm dbh. The stand was typical of other small tracts that had never been cleared of tree cover – some of the hemlock are more than 400 years old.

Dinner and overnight was at the Comfort Inn, Concord, New Hampshire

John Mc Loughlin

Wednesday 15 September

We left the Comfort Inn, Concord and headed north for a one hour's drive to the Hubbard Brook Research Foundation (HBRF), near Woodstock in the White Mountain National Park. As we travelled north to higher altitudes there was a noticeable change in climate and tree species. Hickory, red oak and white pine found on the sandy soil began to give way to sugar maple, spruces, paper and yellow birch, and firs such as balsam fir. Most of the forests we passed though were federally owned.

On arrival at the HBRF, we were met by Steve Wingate, assistant ranger. Ian Halm, site manager and forester, gave an introductory talk.

Tour Convenor John McLoughlin, with Professor Pete Hannah, tour organiser and Mike Bulfin, President of the Society of Irish Foresters.

Hubbard Brook experimental forest consists of 3070 ha, set aside by the US Forest Service in 1955, dedicated to the long-term study of forest and aquatic ecosystems. It is part of the international network of biosphere reserves and provides a standard against which the effects of man's impact on his environment can be measured. The first stream was fitted with measuring devices in 1956. Since then water samples, stream flows, and soil profiles and other scientific measurements have been taken on a weekly basis in all kinds of weather conditions. The average annual rainfall is 1400 mm.

Most of the research work is done by co-operators. The Forest Service acts as a facilitator, overseeing management of the watersheds, providing accommodation to researchers and runs an archive centre. Some 85% of the area is now forested, having been completely cut over pre-1900. People come from all over the world to carry out scientific research.

In 1960 the Hubbard Brook Ecosystem Study was established. The study has involved universities, government agencies; disciplines from botany to geochemistry, limnology to avian biology. One of the most important studies to date is acidity of precipitation in North America. Two excellent reports on the topic have been published:

1. *Nitrogen Pollution: From the Sources to the Sea*
2. *Acid Rain Revisited*

Copies of the reports can be obtained by contacting the Hubbard Brook Research Foundation: hbrook@hbresearchfoundation.org or from the website http://www.hubbardbrook.org

Ten watersheds, ranging in size from 11.8 to 76.0 ha have had V-Notch weirs installed, and these have been used in hundreds of experiments and studies over the last 50 years. The most important recent development has been the purchase of a parcel of land on the shores of Mirror Lake, which has also been used for experimentation. Soils in the catchment have depths ranging from 1-3 m and are very acidic.

A range of experimental fellings have been carried out. Ecosystem appraisals to date show that stream pH has increased. Natural disasters, such as fire, are the most serious threat to the forests. Most damage is done where areas are left uncut as part of an experiment.

Cuttings opened up for experimental purposes vary in size from very small coupes to 4 ha clearings. In some experiments all the timber was removed from the site, while in others the felled trees were left in situ. Species recolonisation, water yield, nitrate release, nutrient loss from the soil, are some of the topics that have been investigated. Nutrient addition experiments have also been carried out, and calcium (4-5 t/ha) has been applied to bring stream pH levels to those recorded 50 years ago. Data were collected year-round, with streams being monitored on an almost hourly basis.

Experiments have also been carried out on bird populations, especially songbirds.

We left Hubbard Brook Research Centre to visit a series of sites in watershed 5. The first stop was at an elevation of 490-760 m. No felling had taken place since the

1900s, with the forest now comprised of large sugar maple, yellow birch, American beech and some American ash. Some paper birch was also present, with hemlock near the streams. Beech was badly damage by beech bark disease. Westerly prevailing winds, coming from an industrialised area, are a source of acid rain. Although sulphur emissions have declined, nitrogen emissions have actually increased. Sugar maple and red spruce are the most susceptible to acid rain. Also the absence of oak from the species mix was very evident. The soil water has a pH of 2.9, the lowest in the area - the objective was to increase this to 5.5. Fish stocks are a very big issue.

An experiment to assess the ecosystem response to whole tree harvesting was carried out during the 1983-4 dormant season, with 180 t/ha of biomass removed. In brief the results were:

1. increase in temperature up to 6°C at the soil surface and in the streams
2. increase in moisture content of the soil
3. increase in stream flow volume of 40% in winter and up 20% in summer
4. increase in nitrification
5. increase in nitrate in soil solution
6. no increase in erosion or sedimentation
7. rapid colonisation by pin cherry, seed of which had remained viable in the soil for decades.

At the second stop water flow data were being collected on weekly basis using a V-notch weir/San Dimas flume. The instrumentation was first installed in 1992.

In the early 1960s, Dr F. Herbert Bormann and others proposed the use of the small watershed approach at Hubbard Brook, to study linkages between hydrologic and nutrient flux, in response to natural and human disturbances, such as air pollution, forest cutting, land-use change, increases in insect populations and climatic factors. As temperature can drop to -20°C in winter a propane gas heating unit was installed to prevent freezing and to allow water samples to be taken. A small coupe had been felled near the gauge in 1983; it is now heavily stocked. Pin cherry, paper and yellow birch, and American beech have all regenerated naturally, with no silvicultural operations being carried out.

Steve Wingate was the tour guide for the afternoon. He is responsible for the management of 3070 ha in the Research Centre. We travelled the Triple I road, which led to the Camp community centre, and was once the old railroad station. The surrounding forest was originally agricultural land. Although silvicultural management was practised, forest recreation was very important in the area – with walking, hunting and skiing the main activities. The silvicultural plan was to fell small 0.2 ha coupes, over 20% of the area at any one time. Restocking was by natural regeneration. By keeping the coupes small it was possible to favour paper birch, American beech, red (sugar) maple, with some aspen.

The next stop was an area that had been had been settled by white people in 1780, and by 1810 much of the land had been cleared for agriculture. Towards the end of the 19th century there was a rapid decline in farming, and by 1890 most of the farmers had left the land. Some forest industries have, however, survived and flourished, such as maple syrup production and bobbin making (using birch).

As industrial development replaced farming, pollution and silting of waterways increased. The absence of forest cover, fear of damage to water quality, together with the demand for public recreational facilities, forced political action. Conservation laws were implemented for some 300,000 ha. Half of the land was managed for recreation and half for a combination of recreation and timber production. No forest management was carried out on areas set aside exclusively for recreation. Timber sales provided valuable revenue to offset the cost of the consultation process, known as scoping.

Timber harvesting was being carried out at the next stop. The area was managed to demonstrate how timber production could be carried out while still protecting the recreational and ecological value of the woodland. The management plan covered a 15-20 year period. About 25,000,000 board feet were programmed for sale, but a detailed and lengthy consultation process had to be completed before the felling programme was agreed. Whole tree harvesting was not permitted, and everything except the main bole was left on the site. Felling coupes were restricted to 0.3 ha for spruce and up to 0.8 ha for hardwoods. There could be as many as 100 coupes comprising each sale. The objective was to use a 100-year rotation, felling small groups at 3 to 5 year intervals, resulting in a more natural, uneven-aged forest.

Consultation involved seven stages:

1. scoping: compiling a list of stakeholders,
2. 30 days for responses,
3. genuine concerns were taken on board and changes made where necessary
4. analysis and reply to stakeholders – with another 30 days to respond
5. consulting with district rangers
6. deciding on alternatives if necessary
7. allow 45 days for objections to the final plan.

The final stop was at a clearfell of about 2 ha of mainly beech (80%), with some yellow birch. Pin cherry was regenerating prolifically on all open sites – the seed had remained dormant, but viable, in the ground for up to 100 years. All logging slash was retained on the site, which created a high nitrogen supply for the regenerating seedlings. Cherry was fruiting after 5 years, providing valuable food for wildlife. Deer caused very little damage; this was more a moose area. Bobcats and lynx were the main predators of deer. Due to actively growing forest, and a lack of old growth, natural fires were not a problem. Baiting to attract bears was allowed in the woodland at certain times of the year and we saw this procedure in progress nearby. Bait is laid in a clearing and the shooters lie in wait for the bears.

Further on, we walked through woodland managed as shelterwood, where 1/3 of the canopy had been removed. The regeneration was being monitored and when the required level is achieved the canopy will be further opened up. Five to seven years later the canopy will have closed over again. There was a question of manipulating the canopy to favour more commercial species, but this was only done in federal forests where commercial forestry was the main objective.

The day finished with a spectacular drive eastwards, from Lincoln across White Mountain National Forest, through the Kancamagus pass to Conway. Climbing the pass we passed through different plant zones; every 300 m increase in elevation being equivalent to travelling 470 km north. A boreal forest vegetation of American beech, hemlock, sugar maple, yellow birch and paper birch occurs at the lower elevations. At the higher elevation, sub-alpine zone, the species composition is mountain ash, paper birch, red spruce and balsam fir. Paper birch had been seriously damaged by ice. After a photo call at the viewing point we boarded the coach and travelled to our hotel in Conway.

Overnight, Cranmore Inn, Conway, NH

Michael Doyle

Thursday 16 September

Day four of the tour started as usual at 8 a.m. as we left North Conway and travelled to Bartlett Experimental Forest, New Hampshire. Bartlett is located in the heart of the New England tourist and ski country.

The group was met by William B. Leak, Chief Research Silviculturist, Mariko Yamasaki, Research Wildlife Biologist and later by Chris Costello, Research Wildlife Biologist, all of whom work for the Forest Service, U.S. Department of Agriculture.

Bartlett Experimental Forest is a field laboratory for research on the ecology and management of northern forest ecosystems. Research activities began in 1931, when the U.S. Forest Service set aside 2,600 acres (1,052 ha) in the White Mountain National Forest in New Hampshire for experimental studies, as part of the then Allegheny Forest Experiment Station (1927-45). This particular site was chosen because it was representative of soil, elevation, climate and tree species composition found throughout New England and northern New York. Podsols, with a rich humus layer predominate, and have developed on glacial till derived from granite and gneiss. In many places the soil mantle is very shallow - boulders and rocks are commonplace. The climate in the Bartlett area, where elevation ranges from 210 to 910 m (the summit of Upper Haystack mountain), is characterised by warm summers and cold winters. Annual precipitation is 1300 mm, evenly distributed through the year.

Research at Bartlett includes:

- investigations on structure and dynamics of forests at several levels, and developing management alternatives to reflect values and benefits sought by users of forest lands
- deriving a better understanding of ecological relationships between wildlife habitats and forest management at various levels, in order to integrate wildlife habitat maintenance and improvement with other forest management goals
- preservation of undisturbed areas in the Northeast US to study natural succession and anthropogenic impacts.

Silviculture/ecology research

In 1931-32, a 100 x 200 m grid was laid down comprising 500 permanent, 0.1 ha square cruise plots. After an initial measurement of all woody stems larger than 3.8 cm dbh, a majority of the plots (441) was remeasured in 1939-40 and again in 1991-

92. This 60-year dataset includes areas (55%) that were cut for experimental purposes using single tree selection, diameter-limit cutting, group selection, clearcutting, shelterwood and thinning. The remainder of the forest has not been harvested since at least 1890. There have been no recent fires, but a hurricane in 1938 did substantial damage, particularly at the higher elevations, and the area sustained severe damage from beech bark disease in the early 1940s. Two other natural disturbances may be occurring - red spruce decline associated with acid deposition, and migration of tree species upslope as a result of climate warming.

Wildlife research

Wildlife relies on the array of forest and riparian habitats located on the extensively forested mountain slopes. Non-forested and aquatic habitats are minor components of the overall landscape. At least 15 species of amphibians and reptiles, 90 bird species and 35 mammal species are known to occur in the area. Moose and black bear occur, as do salamanders and wood frogs, as well as a number of raptors (red-tailed hawk, goshawk, barred owl and saw-whet owl), a number of neotropical migratory birds, permanent residents (pileated woodpecker and ruffed grouse), winter residents (crossbills and redpolls); and an array of bats, small mammals, forest carnivores (weasel, fisher, bobcat), snowshoe hare and white-tailed deer.

The most serious problem facing woodland managers is a lack of knowledge about the ecological relationships between wildlife habitat and forest management in northern hardwoods and associated ecosystems. This information is essential for integrating wildlife habitat maintenance and improvement with other forest management goals, including timber production and maintenance of aesthetic qualities.

The primary objectives of wildlife research are:

- refining and expanding the ecological classification to better define vertebrate species concerns
- evaluating silvicultural effects on wildlife species that use the northern hardwood/mixedwood types
- improving and developing silvicultural prescriptions that effectively integrate timber production and wildlife habitat improvements and
- extending wildlife habitat investigations into forested wetlands, riparian and aquatic systems typically associated with the northern hardwood and associated types of the region.

Research has concentrated on amphibians, birds and small mammals, as there is work being carried out elsewhere on traditional game species. Habitat research on forest carnivores and moose is also carried out.

Our first stop was at a 12/13-year-old group patch selection of white ash (*Fraxinus americana*) with an understorey of American beech (*Fagus grandifolia*) and eastern hemlock (*Tsuga canadensis*). Group patch selection is clearcutting on a small scale, usually no more than 1/3 ha, often within the boundaries of younger or older stands. Natural disturbance cannot be counted on to promote regeneration, as fire risk is minimal.

Eastern hemlock and American beech are not high value timber trees but are important for wildlife. All operational costs are paid for though commercial timber sales. The management plan for the area is to integrate timber and wildlife habitat over time, and is drawn up by an ecologist and a forester. The size of opening and age class are important because they influence bird breeding success. The site had a variety of habitats and microhabitats for birds.

Coarse woody debris is left to favour woodpeckers, carpenter ants and mushroom feeders.

Pre-commercial early thinning (at around 25 years of age) is an expensive operation and often the response does not justify the cost. Where it is carried out 50-100 final crop trees per ha are released. Normally, sites are left until a commercial sale is possible.

Work done in the research forest develops standards for work practices. By consulting with foresters who demonstrate and practice on private land the results filter out to the different kinds of ownership. Workshop tours are also held.

A Sustainable Forest Initiative controls industrial forests, with federal forest land, however, everyone has a say. Water quality and cutting near roadsides are controlled by regulation. The agricultural sector is small in the state so there is not as much pressure on farmers in regard to water quality and is not an issue to the same extent as it is for foresters.

The next stop was a 50-year-old paper birch (*Betula papyrifera*) stand. Paper birch is a good wood-turning species and is also used for shoe pegs and toothpicks. The management plan was to let nature do the work. As a result, the site now comprises an admixture of American beech (*Fagus grandifolia*)/red maple (*Acer rubrum*)/yellow birch (*Betula alleghaniensis*)/white ash (*Fraxinus americana*).

Typically, based on a 120-year rotation, only 1% of area is clearfelled at a time. Loggers have complained that it is more costly to harvest smaller lots and are seeking to harvest larger-sized areas. The outturn from group patch selection is usually half-and-half pulp and saw timber. Logging machinery has become more sophisticated and allows greater site accessibility. With full tree felling the slash must be brought back into the forest and spread out to allow coarse woody debris to build up.

Birds utilise different tree species, so diversity needs to be maintained to provide structural and feeding habitats, and to aid fledgling success. An important factor in the management plan, therefore, is the encouragement of a broad array of tree species.

We moved to a 2 ha 'liquidation' clearcut, done 50 years ago. Loggers were allowed to do as they wished and as a result the area was decimated - the motto of New Hampshire is *Live Free or Die*. A sign saying "Poor cutting practice" was put up on the area when it was clearcut, but it had to take down some years later when it became clear this was not the case. The area was allowed to regenerate naturally and now has a mixture of species growing successfully. Ironically, the potential end value of the timber on the site is higher than if the area had been managed.

The next stop was at a deferred shelterwood of yellow birch (*Betula alleghaniensis*) and white ash (*Fraxinus americana*). The management plan is to leave the area for 30-50 years before going in to open it up to allow species to regenerate. There was a heavy beech understorey and a dense scrub layer, which is good cover for birds, especially thrushes. The area will be left until it can make a good pre-commercial thinning, as it is too expensive to intervene before that time.

Studies of Northern hardwood species have shown that windthrow is not a problem in the area. Overall there is not a lot of natural disturbance as hurricanes are very rare.

The group was joined at the next stop, a 5-year-old clearcut of paper birch/yellow birch and pin cherry (*Prunus pensylvanica*) by Ms Chris Costello. The cherry is used as a nurse species as it has no commercial value, not even as pulp. The area is being used to test different treatment options, using the range of tree species present.

From a wildlife perspective the site provides pre-migratory habitat by birds, with the pin cherry berries providing food. Cherry seed can lie dormant in the ground for 100-150 years before germination, and following germination and growth it can fruit for 20-30 years. Bears and moose occurred in the area.

There is a dramatic increase in bat activity in new open area; nine species occur, one of which is on the Federal endangered list. Three species are migratory while the rest are residents and roost in nearby worked-out mines. Recreational caving during winter disturbs bats' hibernating.

Deer densities are low – just 3 per 400 ha. This is because of the lack of feeding habitat, consequent on low levels of regeneration, and low winter temperatures which militate against survival. Shooting of hinds is not permitted in the White Mountain Area.

We moved to the next stand, managed using a single tree selection system. It was planted as a pure crop of American beech (*Fagus grandifolia*), a shade tolerant species. Interventions were made every 15 years or so, removing between one quarter and one third of the standing volume. Beech is not high value timber. Between 80-90% of stand was affected by beech bark disease (*Nectria coccinea* var *faginata*).

There were nine long-term mammal-sampling points located at the site, where 26 small mammal species have been recorded. Mountain lion (most likely bobcat) is periodically seen. Wolves have been known to move down from Quebec but there is no reproducing population of wolves at present in vicinity. The mountain lion has not been confirmed in New England for several years; recently in persons in nearby Maine claim to have seen mountain lions but no photographic evidence has been produced.

Our final stop of the morning was at a 10 ha clearcut that was now 70 years old. A commercial thinning had been carried out three years ago, removing mature aspen (*Populus tremuloides*) and paper birch. Maples, white ash and yellow birch have been left to mature. The management plan for the site is to leave it for another 50 years; at that stage it may be clearfelled or group patch selection may be carried out. White ash (*Fraxinus americana*) does not show signs of discolouration, which is usually related to early injury. There is no deer problem in the area.

For many years aspen had been discriminated against and was not a focus of management. However, in the opinion of ecologists, who have some influence over species composition of stands, aspen should be grown more, which will encourage more wildlife. Finally it was noticed that yew (*Taxus*) grows in the area but only as a shrub - Pete Hannah told us that in New England deer love yew, and it is thus seldom seen.

Having completed our visit and after a picnic lunch, the three leaders were thanked for their time and enthusiasm, and were each given a gift on behalf of the Society.

Overnight, White River Junction, Vermont.

Bridgid Flynn

Friday 17 September

We headed for the Green Mountain National Forest, where we were welcomed by Chris Casey and Bill Collpepper.

Chris explained that National forests were set up to provide watershed protection and continual forest resources for the nation. They are managed by the United States Department of Agriculture (USDA) Forest Service. Each national forest is part of a larger National Forest System that includes more than 150 forests from Alaska to Puerto Rico.

Green Mountain National Forest was established in 1932 after uncontrolled logging, fire and flooding had ravaged the state of Vermont. Today, the Green Mountain National Forest has grown to almost 160,000 ha, stretching nearly two-thirds the length of Vermont. The forest is within a day's drive of 70 million people.

Half of the forest is available for multiple use forestry and half for conservation. This makes management difficult, but it is achieved by consultation, preservation orders, settlements, appeals and the courts. Since demands vary greatly, reaching a balance is a constant challenge.

With the decline of farming from the early 1900s forest cover has now reached 80%, mostly through natural regeneration. There is a more open landscape in Vermont, evidence of more glacial activity, unlike New Hampshire which has dense forest interspersed with many rivers.

Deer management is an important element of forest management: since 1975 there has been a shift in emphasis to larger clearfells to provide 3-5% open area for over- wintering deer populations.

Our next stop was the Robert Frost Interpretive Trail; a very popular attraction. Frost spent many summers enjoying the surroundings along the trail. Walkers are reminded of his work by plaques along the trail which carry extracts from his work. His best known poem is Stopping by Woods on a Snowy Evening, which includes the famous lines:

The woods are lovely, dark and deep.
But I have promises to keep.
And miles to go before I sleep,
And miles to go before I sleep.

Over the last 50 years in Vermont abandoned farms reverting to forest have more than offset losses of forest cover due to development. It is doubtful, however, if this will continue over time because of the diminished number of farms and increased development pressure from a growing population.

Population increases also influence how the forest is used. Greater demands are now being placed on forests to produce both traditional and non traditional benefits and values. At the same time, parcelisation of timberlands into smaller holdings has made it more difficult to use the forest in traditional ways. Landowners with small holdings are less likely to manage their forests for timber production, and because many of these small tracts also contain homes, their owners may be reluctant to allow others to use their land.

The period from 1948 to the present has been remarkable for the return of Vermont's forest cover. As these forests are maturing trees are increasing in size, and in terms of species composition. Health surveys are indicating that the forests are in a good condition.

The challenge for the future will be to avoid a reversal of that good fortune, while sustaining the delivery of the variety of goods and services that a growing population expects form the State's valuable resource.

Overnight Bolton Valley Resort Hotel, Vermont

John Mc Loughlin

Saturday 18 September

We had a well earned rest in the morning before heading off to Butternut Mountain Farm, Morrisville to see maple syrup production. Our host was the owner, David Marvin who is also a Consultant Forester.

We expected to see the traditional method of harvesting, with a bucket to collect the raw syrup hanging under where the bark was cut. Instead, what we witnessed was a most sophisticated method of production. Sap is collected by a system of crisscross lines over the 400 ha which surrounds the processing unit. The lines collect every drop of sap from the trees for storage in two 75,000 litre (20,000 gallon) tanks. A combination of slope and a large sugar rush make this possible. Prior to boiling excess water is removed, using a reverse osmosis system, which pushes the sap through membranes at high pressure. As well as concentrating the sap this process reduces boiling time, and the holding space required. The system can process 11,000 litres (3,000 gallons) of liquid per hour, producing about 2,000 litres (700 gallons) of concentrated sap.

More than 100 years ago in Vermont, Charles Jones devised what has become known as the 'the Jones rule of 86'. This works on the simple principle that the number of gallons of sap to produce one gallon of syrup will vary with its sugar content. For example, if the sugar content of the sap is 2%, 86 divided by 2 gives 43 gallons of sap to make one gallon of syrup.

Overnight Bolton Valley Resort Hotel, Vermont

John Mc Loughlin

Sunday 19 September

Sunday morning was free and we drove to Burlington, the largest town in Vermont (with a population of 40,000 people), where we took a boat trip on Lake Champlain. With a length of some 50 miles it forms the boundary between Vermont and New York states, and Canada the north.

Overnight Marriot Fairfield Inn, Burlington

John Mc Loughlin

Monday 20 September

Waterbury Vermont - management on state forest lands

Steve Sinclair, Russ Barrett and Diana Fredrick met the group. Steve Sinclair gave a brief outline of the issues and challenges facing the forest industry in the state of Vermont. Over three quarters (78%) of the state is tree-covered (2 million ha). Ownership is mainly private (80%). The overall health of forest stands in the region is thought to be improving.

Uneven age class spread is a problem for forest management. Another problem is the continuing fragmentation of already small ownerships (average 20 ha), due to road and house building. An additional problem is the falling number of people hunting deer, leading to an increase in deer numbers and the resulting problem of securing successful natural regeneration.

Diana Fredrick led the group through an impressive 70-year-old stand of white pine. Prices for standing timber have been rising for a decade, and are continuing to rise. Sales are made on the basis of dbh and height. Pine sells for $150/1000 board feet, compared with $700 for sugar maple. All revenue from sales on state forestlands goes to central coffers.

The local sawmill industry suffers from competition from Canadian mills, which are a short distance (100- 160 km) away. They have a cost advantage due to government support (0% interest, health insurance advantages etc.) and transport costs are low due to backloading on lorries that bring softwood lumber into the US.

Harvesting in the state is moving from grapple skidder and chainsaw felling, to feller buncher and forwarder/grapple skidder.

Beaverbrook (Marshfield)

We visited privately owned woodland in the afternoon, led by Richard Carbonetti (forest consultant) and Russ Barrett. The owner had bought the property mainly for developing it for skiing and orienteering, It would normally attract a land tax of $114/acre/annum but this was reduced to $2.50/acre on agreeing to manage the area under a 10-year plan. Together with the owner Richard had drawn up a plan, which had as its main objective to manage the woodland in a sustainable way, compatible with the recreation objectives.

The woodlands comprise areas of spruce and cedar, mixed broadleaf and conifer, and pure broadleaves. An area of 32 ha (80 acres) has been left unstocked, including a small lake. The previous owners had a policy of minimum management with a primary focus on wildlife promotion. The shape and composition of the property has been influenced by the hurricane of 1938 and the ice storm of 1998. The damage and disruption caused by the 1998 storm had in fact led to an increase in harvesting and regeneration, which allowed the management of the property to be brought up to date.

The return from felling was in the region of $500-630/ha per harvest period. Each year's increment adds about $40/ha, on a 15-year thinning cycle.

White pine is harvested using a full tree system, with assortment segregation into veneer and other products taking place at the mill. Harvesting on wet, soft areas is done when the ground is frozen; the maximum skid distance for the property is 400 m. The main aim of thinning is first to enhance recreational value, with a secondary silvicultural objective of removing fir from white pine and cherry stands, and less valuable species from yellow birch and sugar maple stands.

A discussion on the constraints imposed on the forest industry by the green and suburban lobbies highlighted a common complaint heard during the tour. These restrictions thwart the proper and beneficial management of forests in the state; interventions that were badly needed could not be done, especially on state lands, as these offended the sensibilities of the lobbies. Clearfells that would allow valuable species such as yellow birch, sugar maple and red oak to establish were not permitted, and those thinning interventions that were allowed tended to favour less valuable, shade-tolerant species. Additionally, the constraints placed on the processing industry were causing problems in terms of being able to sell small lots – due to distance from mills.

Deer control figured largely management plans; high levels posed problems for regeneration. The problem is being tackled by encouraging hunting.

Overnight Eastgate Motor Inn, Littleton, New Hampshire

Paddy O'Kelly

Tuesday 21 September

As the tour departed Littleton our attention was drawn to the strip shelterwoods found in the area near Goram. These natural stands of white birch established themselves due to the influence of fire on the mountain vegetation. The slash on the ground is often burned by frequent forest fires in the area, and white birch can withstand the impact of fire as it passes. Fires are uncommon these days. In the past during heavy logging in the White Mountains fire was common, and any birch that survived in the clearcut, or birch on the perimeter was the source for natural seeding of birch following the fire. Expanses of white birch merged into areas of pure paper birch - the raw material for a local pulp industry.

We crossed the state boundary at Gilhead and entered Maine. Here the changing leaf colour during autumn is spectacular and is a lucrative tourist attraction. It is widely publicised - visitors are welcomed by signs such as "welcome leaf peepers". Three factors influence autumn leaf colour: pigments, length of night and weather. The timing of colour change and leaf fall is regulated by the increasing length of night - as days grow shorter and nights grow longer and cooler, biochemical processes in the leaf lead to a colour change and consequently a dramatic change to the landscape.

There were two mills in the area, in addition to preparing chips for the paper industry they are diversifying into toys and dowels.

Proceeding through the village of Bethel we crossed the Androscoggan River – used in the past for log transport. Small rivers were dammed up with small logs which were then released to flow at a fast pace down to the lowlands where they were collected and sawn, or transported to other locations. The last log drive on the Androscoggan was in 1976, when the practice ceased due to debris damage to the river and a resultant detrimental effect on fish life.

The main stop of the day was a visit to a natural forest management site, managed by the Seven Island Land Company. The site is part of a 610,000 ha (1.5 million acre) holding which came into the ownership of a family in 1840, and is now extending to the eight generation. We were introduced to John McNulty who is in his twenty seventh year of employment with the family.

The natural forest management system involves no planting. During the thinning operation certain species are selected and left to grow to maturity. Factors such as species' life span and predicted future markets for the species influence the selection process. In this forest balsam fir has a shorter life expectancy than the spruces. Red maple is considered inferior to sugar maple - so the spruces and the sugar maple are retained if possible.

The thinning operation is carried out by a circular saw attached to a long arm on a machine which fells and then tows approximately five felled trees to the loading area on the roadside. Here the trees are debranched by the same machine and crosscut into the required lengths, which are then stacked to await collection by the timber trucks. The first cross cut is made at 20 cm diameter, with the length above classified as pulp and cut at 7 cm.diameter top diameter. Lengths below the 20 cm.diameter point are classified as sawlog.

When the branches build up at the loading area they are dragged back into the thinned – the operation is called 'carry back in' - and are spread over the thinned area.

About 750,000 m3 of roundwood is harvested per year, with 80% being harvested using the method outlined. The haul distance is planned to not exceed 500 m. The mill is 125 km distant, with truck and load weighing 55 tonnes.

The next site had a shallow hardpan soil; some drainage had taken place, which had improved the quality of the hardwoods. The area was regenerated in 1938 and now comprises mainly spruce and fir. Aerial application of herbicides is permitted in Maine; this relaxation of regulation has proved beneficial in managing forests.

We moved to the Rangeley Lake Heritage area of the forest, to an amenity area which is used mainly at weekends for boating and other outdoor pursuits.

Finally, we were taken to an area that had undergone a number of thinnings over a period of time – with stems generally well spaced and a very promising crop of sugar maple and white ash. These will be grown to a breast height diameter of 30-38 cm, when they will be felled for commercial sawlog. The 'carry back in' material was still evident throughout the area, but had decomposed to some extent.

So ended our first day in Maine, a state that has 90% forest cover, and which provides a return on investment of 6-8% real in terms.

The diverse ownership of forest land in Maine has led to it having a distinct forest policy and Forest Act. One manifestation of this policy is the limitation placed on clearfell size: up to 8 ha (20 acres) there are no restrictions, larger areas up to 30 ha (75 acres) require a plan to be submitted, but no permission is required, and for areas up to 70 ha a certain amount of the area must be set aside for a number of years.

Dinner and overnight Lafayette Fireside Inn, Auburn, Maine

Frank Nugent

Wednesday 22 September

We drove to Gray in Maine to visit red oak and white pine forests. We were met Clifton F. Foster, a Consultant Forester for 40 years and also a forest owner, and Steve Chandler the forest owner. Steve owns 1,200 ha of woodland that has been in the family since the 1700s. Urban sprawl is now putting pressure on the forest land.

The main soils in the area are Buxton silt loam and Paxton very stony fine sandy loam. Both of these sites are classified as Class 1 for tree growth.

Hardwood trees require deep, moderately well drained soils for maximum growth. Root penetration is at least 60 cm on these soils, which hold water very well. Of all soil attributes drainage is the most important, as it affects not only the water regime but soil fertility and aeration which are important for tree growth. Tree vigour is also superior, particularly when it comes to resisting insect and disease attacks: these soils provide that vigour.

Soils in Maine are highly variable; a single woodlot can contain 10 or more soil types. However, soils can be grouped by drainage classes and managed accordingly.

Stop 1, white pine was cut in 1910 and re-grew naturally; it has been thinned five times since 1955. The crowns are now suffering from die-back due to ice damage. The crop was pruned which was a costly investment.

Stop 2 was a site that was planted with white pine (Pinus strobus) after ripping. Due to competition from red oak the pine was being drawn up, resulting in good height growth.

Stop 3 was a crop of white pine, planted 12 years ago through grey birch, with the pine growing well through the competition.

Stop 4 was at an oak/pine mixture. White pine weevil does not like shade, the oak will be taken out when the pine reaches a sufficient size and the threat of weevil damage recedes.

Stop 5 was at gravel pit, with an adjacent aquifer. More gravel could have been removed but the aquifer had to be considered. Red and white pine will be planted when the extraction ceases at the pit, as they grow well on gravel.

Stop 6 was a stand of 3-year-old white pine planted in mixture with red pine. There is a symbiotic effect which benefits both species. However, ATVs (all terrain vehicles) driven for by townspeople have in some cases destroyed up to 80% of the young trees.

In the afternoon we visited Freeport, Maine and after an al fresco fish meal we bade goodbye to our genial host Professor Pete Hannah for being such a wonderful and informed guide.

Dinner and overnight Lafayette Fireside Inn, Auburn, Maine

John Mc Loughlin

Thursday 23 September

In the morning we headed south to Boston where we had some time to sample the city before heading to Logan Airport for our departure home.

John Mc Loughlin

Participants:

Peter Alley, PJ Bruton, Michael Bulfin, Michael Carey, Richard Clear, John Connelly, Jim Crowley, Michael Doyle, Ken Ellis, Jerry Fleming, Brigid Flynn, Matt Fogarty, Tony Gallinagh, Sean Galvin, Christy Hanley, George Hipwell, Liam Howe, Larry Kelly, Eddie Lynagh, PJ Lyons, Tony Mannion, Ted McCarthy, Pat McCloskey, Kevin McDonald, Tom McDonald, Michael McElroy, Jim McHugh, John Mc Loughlin, (Convenor), Brian Monaghan, Liam Murphy, Jim Neilan, Frank Nugent, Michael O'Brien, Pat O'Callaghan, Liam O'Flanagan, Derry O'Hegarty, Paddy O'Kelly, Tim O'Regan, Denis O'Sullivan, Joe Treacy, Coleman Young.

Sixty-second Annual Study Tour Scotland 19-23 September 2005

The Annual Study Tour took place 19-23rd September 2005 to SW Scotland. Twenty five persons took part with participants based in the North West Castle Hotel, Stranraer. It proved to be an interesting and informative tour covering private estates, Forestry Commission and community forests. There were also visits to Port Logan Botanical Gardens, Glenlee Estate – magnificent tall trees – and a small local sawmill producing garden goods. Recurring forestry themes were: forest multi-functionality, community involvement in forestry management, wood energy and poor timber prices.

The problems of estate management in Scotland were summed up in a recent quote *despite connections and esteemed history, no estate is exempt from the challenges of modern day management and must continually look to alternative services of revenue to keep the ship afloat.*

Blairquhan Estate
About 610 ha, including 400 ha woodland. Main activities included beef production, forestry, fishing, shooting, holiday chalets, and corporate entertainment. The forest management plan included fishing and shooting inputs with an overall aim of Continuous Cover Forestry (CCF) incorporating selection felling and control of the grey squirrel problem.

Graiglaw Estate
It comprised about 2,500 ha including 120 ha woodland. Most of the farmland – 2,000 ha – was leased to neighbouring farms with timber production and game management the mainstay of the forest management plan. Since 1994 the family house has had its heating provided by a woodchip boiler, utilising chips from small roundwood thinnings, passed through a mobile wood chipper and. Some clearfelling of mature Sitka spruce/pine had taken place and the owner was of a mind not to replant considering the current poor timber prices - £12-15 (€18-22)/tonne, standing.

Forrest Estate
Extended to some 3,000 ha forest and 1,000 ha open ground. High elevation Sitka spruce forest mainly on peat and peaty gley, with an average yield class of 16. The estate was self-contained with own forest staff, harvesting and road construction crew, and an estate sawmill. All Sitka spruce crops were thinned; clearfells were sold standing. The sawmill serviced the estate and local fencing needs. No preventive measures were taken against fomes (*Heterobasidion annosum*) at thinning or clearfell stage, the rationale being that with a damp climate (1,750-2,500 mm annual rainfall) and acid soils, there is a very low risk of infection. A feature of the forest

was a 40 ha lake which powers a small 500 kv electric turbine which feeds the national grid. In economic terms, electricity was reckoned to be as valuable as timber!

Graigengillen Estate

It stretched to some 1,250 ha, with 275 ha of it woodland, and beautifully located in a sheltered fold in the hills of the southern uplands. Work on the estate includes organic sheep production, fishing, horse-riding stables and the restoration of the woodlands, which have suffered from severe neglect. Riparian areas, alongside fishing streams have been planted, add to the woodland area. Landscape values are a constraint on the practice of agriculture and forestry. A feature of the estate forest management is its involvement with the local community, itself an unemployment blackspot, in a sense of "shared ownership", together with provision of public access and recreational amenities. We left the estate via a pleasant riverside walk Lough Doon Hydro Electric Station.

Glenlee Park

The specimen conifers on view at Glenlee owe much of their reputation to the late Alan Mitchell of the Forestry Commission who measured the trees on various occasions over a 30-year period and wrote about them in Scottish Forestry (1979). Specimens included:

- A European larch at 47.2 m (155 ft), and recorded as the tallest European larch in Great Britain or Ireland,
- Douglas fir - several fine specimens with the tallest at 50.9 m (167 ft),
- A Wellingtonia at 46.6 m (153 ft) - its leader was lost some years ago.

There are also specimens of Low's fir (*Abies concolor*), western hemlock and some fine old oaks. The Glenlee woods overall are a designated Site of Special Scientific Interest (SSSI).

Logan Botanic Gardens

Logan is a Regional Garden of the Royal Botanic Gardens, Edinburgh. Located at the southwest tip of Scotland, with the warming influence of the Gulf Stream, the gardens have a remarkable collection of plants from the world's warmer climes. Nearly half of the species were collected from the wild, with most are from the southern hemisphere. The garden shows the majority of antipodean tree forms and gum trees, massive gunnera, fragrant rhododendrons, together with the vivid colours of South African flowers.

Galloway Forest Park

Located in SW Scotland, it is owned by Forestry Commission Scotland and is some 96,000 ha in extent. The Forest Park, with some 56,000 ha of commercial forest, is managed to SFM principles and multi-functionality. Visitors are catered for in three main visitor centres – Glentrool, Clatteringshaws and Kirroughtree. Forest visitor facilities include forest drives, walking, hill-climbing, cycling (including mountain track cycling), horse-riding, fishing, wildlife viewing and simple family fun. Also of interest is the Cree Valley Community Woodlands Trust Forest. It is 60 ha site, part of which is ancient semi-natural woodland, which links in with the RSPB Wood of Cree Reserve and the riparian woodlands at Brigton. The wood is managed by the community, for the local people and visitors alike, and is an excellent example of a community forest.

The commercial forest, predominantly conifer and Sitka spruce, performs a clear multi-functional role in the Park. Up to 40 forest landscape design plans are in position to deal with clearfell and restocking, and while clearfell coupe size may be up to 100 ha on occasion, 15/20 ha is the average. Restocking incorporates broadleaf groups, open space with set-backs from roads, rivers, streams and lakes, long-term retentions, Scots pine, larch, birch, and rowan planting for landscape colour, commercial Sitka spruce planting and deer management/control. Regeneration of commercial species is encouraged and managed.

The Tour Director and organisers wish to record their appreciation of the generosity and hospitality of our hosts and tour guide in making the tour informative, enjoyable and sociable.

Tony Mannion
Tour Director

Obituaries

Seamus Mc Menamin
1912 - 2006

Seamus Mc Menamin died on the 4th of January 2006 aged 94 years. Seamus was a native of Stranorlar, Co Donegal. His pre-forestry training included study periods at Warrenstown Agriculture College and the Albert Horticultural College, Dublin. He joined the then Forestry Division, Department of Lands in 1933, entering the Forestry Training School at Emo Park, Co Laois with 10 other students. The training was largely practical with experience in nursery work and forest establishment at Emo Park and outlying forest properties such as Coolbanagher and Shaen. During this time training was discontinued at Emo Park and facilities transferred to Avondale House, Co Wicklow.

Following the completion of training in 1936. Seamus was assigned to a number of forests, namely Coothill. Cratloe, Carrick-on-Suir (where he was appointed Forester in Charge), Pettigo, and Durrow. In 1942 he was involvedin the founding of the Society of Irish Foresters and remained a life long member. Also, while at Durrow, he was involved in the setting up of the State Foresters Association where he served as a Council member. While on the SFA Council he devoted a great deal of time and effort towards furthering the conditions of foresters, especially in the seeking of establishment status, which eventually happened in 1954.

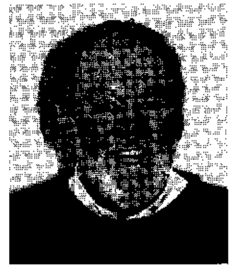
In 1950 he was successful in the competition for Grade III Inspector and was appointed as Assistant District Inspector in Galway. It was during his period as Assistant District Inspector that he was associated ~ith the establishment of many new forests throughout counties Galway and Mayo. In 1957, he was promoted to fue post of District Inspector in Galway. In the 1970s, he became Divisional Inspector for the Westem Region, with headquarters in Galway.

Seamus was meticulous in everything he did and set and demanded high standards. He had a particular gift for expressing in a clear and concise form his ideas on many subjects. He had an inquiring mind with a very keen interest in forestry and the people associated with it and one could not but be amazed by his memory for place names, dates and people. He will be best remembered for his dedication to work and his kindness and consideration for others.

He enjoyed good health throughout his long retirement and his love of walking kept him active to the end. His wife Brid, whom he married in 1939, pre-deceased him by two years. He was very much a family man, and to his children Maura, Sean and Brian, we offer our deepest sympathies.

Brendan J. Collins

Michael Lillis
1948 - 2006



The untimely death of Michael Lillis, our esteemed fellow member of the Society, took place on July 16th 2006 in Kilcloone, Co. Meath in the loving care of his family. Born in Lisaleen, Patrickswell, Co. Limerick on August 8th. 1948 he was educated in the nearby Adare Christian Brothers School up to Leaving Certificate and spent a year in Pallaskenry Agricultural College before entering the Forestry Training School at Kinnitty Castle, Co. Offaly in 1967. He completed his studies at the Shelton Abbey School in 1970. Michael during his studies showed himself to be a bright, intelligent and forward thinking young man so much so that his contemporaries saw him as an influential visionary.

Michael' s career as a forester saw him posted to forest centres at Athenry Co. Galway, Anner Co. Tipperary, Killorglin Co. Kerry, Ross Co. Galway and Lough Graney Co. Clare in the first six year of his service. He spent fourteen years working in Lough Graney during which time he was secretary of the State Foresters Association of the Union of Professional and Technical Civil Servants and was a significant contributor in the greatest change involving Irish Forestry when the commercial state company Coillte was incorporated.

In 1990 he was promoted to Staff Development Manager in Coillte and he took on this new challenge with youthful enthusiasm and subsequently led him to make further impact on the changing landscape of public and private forestry in Ireland. He saw continuing education as an important aspect in the life of employees of the forest industry and he personally exemplified this by graduating with a Management degree from the Irish Management Institute and a Masters degree in Adult and Community Education from the National University of Ireland Maynooth. He was instrumental in and facilitated the awarding of a formal qualification to foresters that received their training in the public service schools.

He promoted the aims of the Society in all his dealings with forestry people and actively recruited new members.

Michael was a key activator in the many contacts between Finland and Ireland, especially between the forestry companies Metsahallitus and Coillte, and initiated many personnel exchanges between the two countries of both forestry students and foresters alike. He was an esteemed ambassador of Irish forestry at the University of Applied Sciences in Oula, Finland where he encouraged them in their first steps in internationalisation and participated in an European Union project with input fromfive European countries concerned with enhancing the teaching of collaborative planning of natural resources. Michael had an extraordinary interest in the literature, traditions and cultures of people living in the countryside be that in Ireland or Finland. He was a committed exponent of the Irish language and always felt privileged when given an opportunity to use it. He loved sport and gave much of his life to Cumann Lúthchleas Gael and his leadership and inspirational qualities are testified in both the Feakle, Co.Clare and Blackhall Gaels Co. Meath clubs. In failing health and two months before he died he was more than pleased as a proud son oí Munster to be present in the Millennium Stadium in Cardiff when his beloved team were crowned European Rugby Champions.

Ba rnhaith liom combhrón a thabairth ar son Cumann Foraoiseóirí na h 'Éireann, agus ar son rnhuintir foraoiseóirí go léir ar bhás Michéal O'Laighléis lena rnháthair Patsy, lena,dheartháireacha is a dheirfiúracha agus go mór rnhór lena bhean chéile Marie agus a thriúr iníonacha Cíara, Siobhán agus RóisÍn.

Bhí tú uasal, dílis, grárnhar i gcónaí, agus ní dhéanfaimid uilig dearmad ort go deo.

A Mhichíl, a chara, go luífidh tu faoi shuairnhneas i dtalarnh chaoin chneasta na Mí.

Ar Dheis Dé go raibh a anam dílís.

Joss Lowry

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