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

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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

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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.

Belturbet

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 Cootchill (COO) provenances were best described as hybrids.

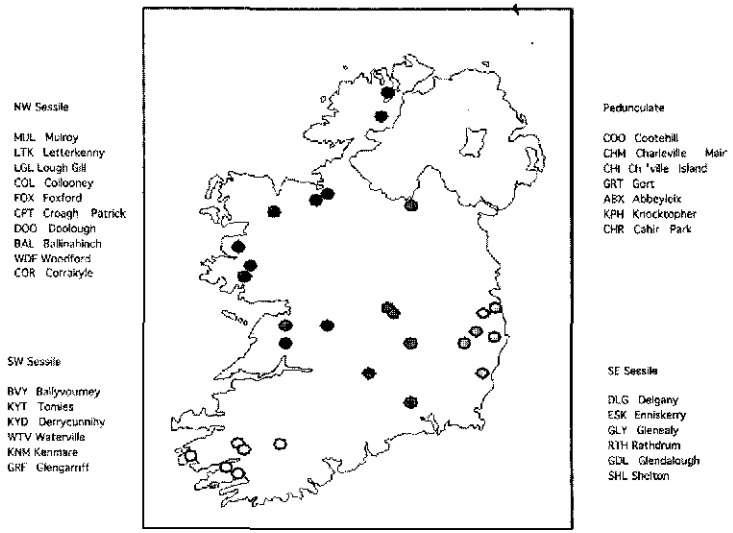

Figure 1: Geographic and species groupings attributed to oak provenances, together with codes.

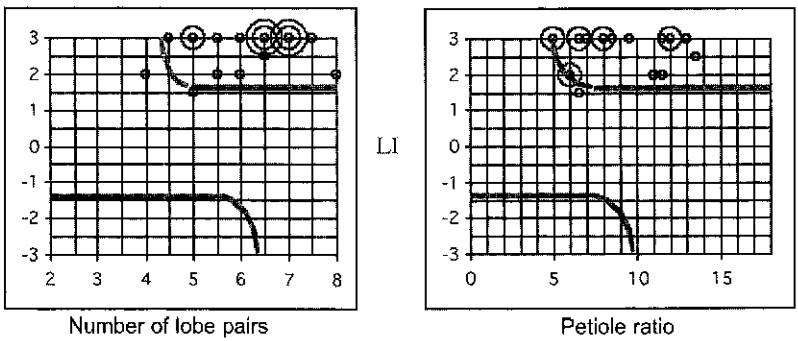

Figure 2: Typical sessile oak scatter diagram Killarney Derrycunnihy (KYD).

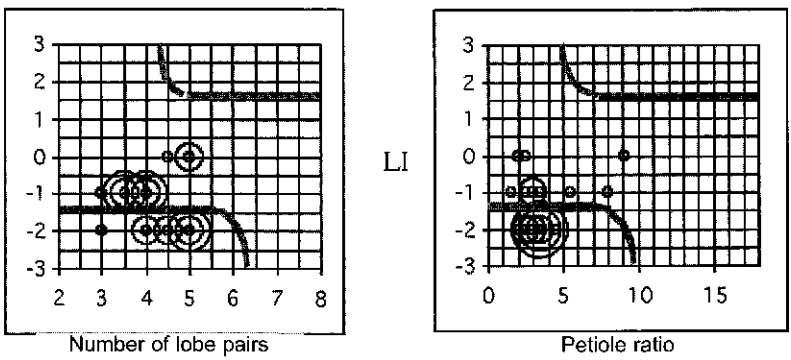

Figure 3: Typical pedunculate oak scatter diagram Abbeyleix (ABX).

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)		B3	
		Mean	Range	Mean	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*

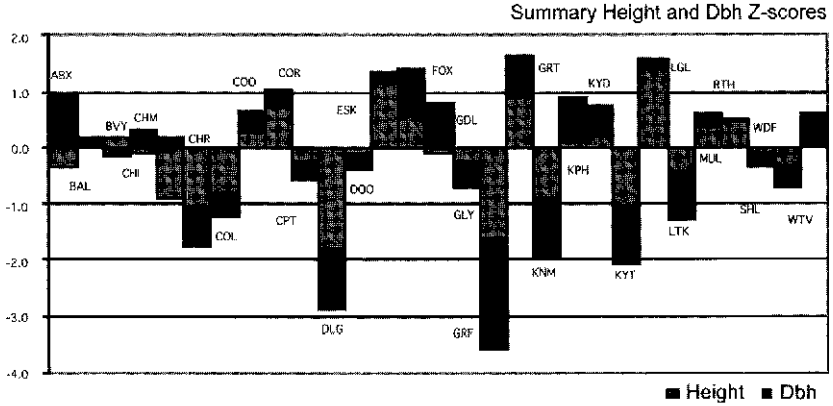

Figure 4: Summary of height and dbh Z-scores for Best 3 data.

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)		B3	
		Mean	Range	Mean	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)

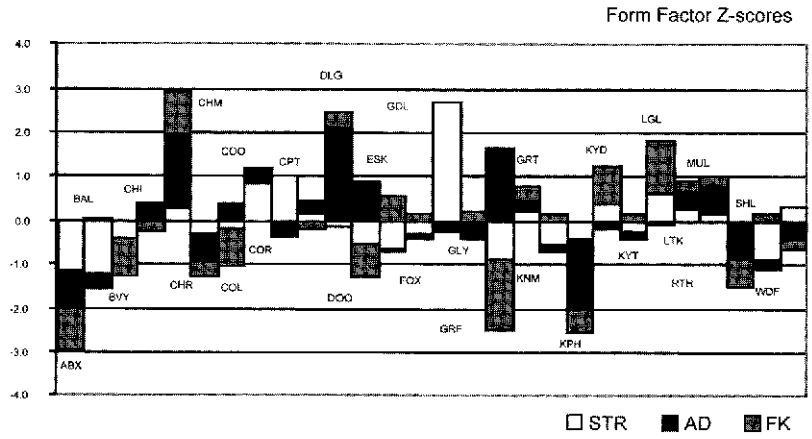

Figure 5: Summary of form (straightness, apical dominance and forking height) Z-scores for Best 3 data.

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	CIII	Island	Offaly	Ped	3	3	3	4
Charleville	CIIM	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.*