FUTURE TREES

TRUST

OAK GROUP BUSINESS PLAN

November 2016 - 2021

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Note 1: throughout this document, reference is made to categories of Forest Reproductive Material (FRM). These are *source identified*, *source selected*, *qualified* and *tested*, indicating increasing levels of selection and genetic gain.

Note 2: throughout this document Britain refers to England, Scotland and Wales, and Ireland refers to the Republic of Ireland and Northern Ireland.

Note 3: This document provides details of work in progress. Data presented are correct as of November 2016.

Glossary

Accession number: a nine digit code assigned to a unique genotype.
Breeding value: the worth of an individual's genotype, as judged by the average value of its offspring.
Breeding Seedling Orchard (BSO): designed to combine the testing of progeny with future seed production.
Chloroplast DNA (cpDNA): Highly conserved DNA located in the chloroplast.
Clonal archive: a collection of grafted (cloned) individuals, brought together for conservation purposes and from which grafting material may be obtained to make further copies of an individual.
Coding regions: the portion of a gene's DNA that codes for protein.
Clonal Seed Orchard (CSO): a seed production unit comprising several ramets of grafted genotypes.
Deoxyribonucleic acid (DNA): a molecule that carries the genetic instructions used in growth, development, functioning and reproduction.
Forest Reproductive Material (FRM): the generic name for seeds, cones, cuttings and planting stock used in forest establishment. There are four categories (see below).
FTT Future Trees Trust: a charity of the United Kingdom and the Republic of Ireland, dedicated to hardwood tree improvement and resilient woodlands.
Genome: the complete set of genes or genetic material present in a cell or organism.
Genotype: the entire genetic constitution of an individual.
Haplotype: a group of genes in an individual that are inherited together from a single parent.
Mitochondrial DNA (mtDNA): DNA located in the mitochondria.
Mitotype: A mitochondrial haplotype.
Phenotype: the observable characteristics of an individual, as determined by the genotype and its environment.
Ramet: a grafted copy of a genotype.
Repeat sequence DNA: patterns of nucleic acids (DNA or RNA) that occur in multiple copies throughout the genome.
Single Nucleotide Polymorphism (SNP): the most common type of genetic variation, each SNP representing a difference in a single DNA building block (nucleotide).
Simple Sequence Repeat (SSR): a sequence consisting largely of a tandem repeat .

<u>Categories of FRM</u>

Source identified (SI): comes from general of specific locations within a single region of provenance or seed zone altitude band in which no superior qualities are recognised.

Source selected (SE): collected from stands showing superior characteristics, e.g. better form, growth rate and health.

Qualified (QU): derives from the selection of superior individual trees which have not undergone any form of testing.

Tested (TE): derives from the selection of individual trees or stands that have undergone evaluation for genetic quality or have been shown to be superior, in comparison to accepted standards.

1. Introduction

There are 219,000 ha of oak in Britain (Forestry Commission 2015) and 17,000 ha in Ireland (Forest Service 2013). Most of this (167,000ha) is in England while Scotland and Wales account for 26,000 ha each. In general the overall quality of the resource is mixed. This reflects the lack of any coherent tree improvement effort in the past along with a management practice that tends to remove the better performing trees when they reach merchantable size, in what can be termed 'negative selection'. This short-sighted practice is carried out to meet the needs of the timber trade and the woodland maintenance cost for the owners.

The Future Trees Trust (FTT) Oak Group (formerly the BIHIP Oak Group) commenced its improvement programme in 1997 with the establishment of a large scale plus-tree selection programme. This was designed to select approximately 250 elite trees across the oak woods of Britain, Ireland and part of north-western Europe. The selection was based on vigour, straightness, lack of epicormic branches, good apical dominance, light branching, good circularity and superior growth and a freedom from insect and disease attack. The selected trees were then subjected to wood tests designed to identify those with small early wood vessel size. Vessel sizes are considered an important measure in the vulnerability to shake in oak and those with larger vessels (160 µm radii and above) are considered more susceptible to shake (Savill and Maher 1990).

A sound strategy is needed to guide implementation of the improvement programme in both the short (5 years) and the longer term. The Oak Group Breeding Strategy (Boshier 2010, unpublished report) gives detailed information on the genetic status of oaks in Britain and Ireland and highlights issues from a breeding perspective that are addressed in this business plan.

The FTT oak group has 13 members from across the forestry sector throughout Britain and Ireland within a structure that includes a chair, vice chair and secretary with a key role in providing leadership and administration to the group. The overall aim of the group is to produce improved seed or possibly micro-propagated material that will maximize the economic benefits from tree improvement gains in wood quality, recoverable volume and pest resistance by supporting the conceptual and operational frameworks for oak tree breeding activities and identify offspring with increasingly superior traits. The Business Plan defines activities and associated funding to achieve this aim.

2. The Oak Breeding Programme

The three principle objectives of the oak breeding programme are:

1 To secure, conserve and utilise key genetic resources of selected oak plus trees and registered seed stands for production of improved forest reproductive material and to work towards the provision of an adequate supply of this improved material to commercial forest owners in Britain and Ireland.

2. To enhance and increase the volume of recoverable high quality oak timber per hectare for the woodland owner by using genetically improved reproductive material accompanied by promoting the best silvicultural practices for oak production. Increase the value and quality of the oak timber produced.

3. Provide information and support on the best oak seed sources to the nursery trade and other key players including forest and woodland owners.

3. State of Current Knowledge

3.1 The role of oak in forestry

In Ireland much of the afforestation up to the 1980s was driven by the state and dominated by coniferous species, particularly Sitka spruce. However, since the mid-eighties, the balance has shifted in favour of the private sector and with better sites becoming available broadleaves began to play a greater role, particularly oak. Today planting levels of oak in Ireland are approximately 550 ha per year and, according to the most recent forest inventory (Forest Service 2013) there are currently over 17,000ha of oak forests in the country.

Forests in Northern Ireland cover 8 % (112,000 ha) of the total land area, and are dominated by conifer species. Approximately 58 % is state owned with the remainder represented in small under managed woodlands in the private sector. However, the majority of this is made up of broadleaved species, with oak plantations accounting for less than 1 % of the total land area.

In Britain oak is the standard, the best known tree in the lowlands and well into the uplands also. Oak's excellent potential is achieved on good fertile sites and rewards skilled, consistent management over a long period. The old tradition of collecting acorns from known fine stands of oak, to be used elsewhere has borne long-term fruit on many private estates. Young trees, damaged by grey squirrels are a frequent and sorry sight at present leading to the current reluctance to plant new oaks but with increased private and public concentration on controlling grey squirrels it will become important to restore oak to sites where it has flourished in the past.

3.2 Current oak seed supply in planning for timber production in Britain and Ireland.

For reforestation purposes in Ireland, the first choice is material from Irish registered seed stands. If Irish material is unavailable, then the material is sourced from registered sources mainly in Europe, sometimes from Britain but generally from the Netherlands. Present demand for planting stock far exceeds available harvestable supply of acorns from Ireland. Ireland reports an annual requirement for oak seedlings over the period 2007-2016 of 3 million, requiring 35,000 kg of seed and 10 ha of orchards (Cahalane *et al.* 2007).

A survey of British nurseries in 2002/3 reported just over 3 million *Q. robur* plants sold, and 1.75 million *Q. petraea*. Assuming 200 germinable seed /kg for *Q. robur* and 250 seed /kg for *Q. petraea*, gives a demand of 30,000 kg of seed per year for *Q. robur* and 22,000 kg seed per year for *Q. petraea*. A realistic yield for a BSO a year is 4,000 kg/ha giving a requirement of 15 ha of orchards for *Q. robur* and 7 ha for *Q. petraea* assuming cropping every four years. As in Ireland, the first choice is often for British provenances and often of local origin although increasingly, near continental sources of planting stock are being recommended. The Forestry Commission recommend including some material from 2° south of planting site, and a small amount from up to 5° south of planting site to ensure resilient populations able to cope with climate change (Ray *et al.* 2010).

3.3 Variation among seed sources

Two series of oak provenance trials were established in Britain in 1990 and 1992. These trials contain both continental European and British provenances and a mix of pedunculate and sessile oak. The trials have now been assessed twice for height, at years 6–8 and years 10–13. Analysis of the height and survival data has shown that British *selected* seed stands have consistently good height growth and survival on all but the most testing sites. Near continental sources of similar maritime climate are generally average in performance whereas Danish and eastern European provenances have performed poorly. British provenances from non-selected stands have shown a range of performances. Those from Scotland, when moved south, have grown slowly but showed better survival on a frost prone Scottish site. On more testing Scottish sites, northerly provenances should be used to reduce the risk of frost damage (Hubert 2005).

Ireland has an extensive series of oak provenance trials (Huss *et al.* 2016) developed in years when an adequate oak mast was present. The earliest of these trials were established at four sites in 1988 at Camolin, Co Wicklow; Durrow, Co Laois; Belturbet, Co Cavan and Donadea, Co Kildare (Felton *et al.* 2006). The objectives of these provenance trials were:

(1) to identify the best seed sources of native oak for commercial purposes,
(2) to examine the genetic variation within and between native oak provenances,
(3) to provide a basis for further ecological studies, and
(4) to create a gene pool to safeguard threatened oak genetic resources.

Results show that a number of provenances performed well at all sites, although best and worst performers show a discontinuous geographic distribution. For example in Wicklow the Enniskerry provenance performed very well while the close-by Delgany provenance performed poorly. This pattern was repeated in Killarney and Sligo. Generally, the younger a tree can be picked as a winner the greater the gain per unit of time when setting up a breeding programme, hence the interest among tree breeders in juvenile-mature correlations. The 1988 trials have been assessed several times (1995, aged seven; 2002-2004 aged 14-16 and 2011-13 aged 23-25). The results showed that there is little to be gained by early selection due to the low correlations (mostly below 0.31) between the traits assessed over the years (Kennedy 2015).

A second in this series of provenance trials was established in 2005/06 at None so Hardy Nurseries, Shillelagh, Co Wicklow; Tullynally Estate, Castlepollard, Co Westmeath and at the Manch Estate, Bandon, Co Cork while a third series of trials was established at two sites in 2008/09 in Camolin Park, Co Wexford and again at Manch Estate, Bandon, Co Cork.

3.4 Silviculture and management

This section gives only a very brief summary of some of the main points that need consideration. A much more complete account of the silviculture of the two species is given in *The Silviculture of Trees used in British Forestry* (Savill 2013) which deals with climatic and site requirements, silvicultural characteristics, epicormic shoots, shake, pests and diseases, natural regeneration, flowering, seed production and nursery conditions, conservation, provenance and breeding, and timber and its uses.

A point that is frequently ignored when planting oaks is proper consideration of the site requirements of the two species (*Quercus robur* and *Q. petraea*). Pedunculate oak grows best mostly in the English and Irish lowlands on heavy, moister, richer and especially basic soils, while sessile oak, which is more drought tolerant, is characteristic of deep, freely-draining, drier siliceous soils in the north and west. Both species tolerate an extremely wide range of soils and often grow together. They are much less site-demanding than many other broadleaved trees. The ranges of the two species frequently overlap, and planting over many centuries has obscured the differences in the natural ranges.

The current price curve for oak timber puts most money on veneer butts, then barrel staves, first quality planking, beam, lower grade planking and finally fencing, before dropping to firewood grades. The first two are rare in Britain and Ireland, requiring slow and even growth of 8 to 10 rings per centimetre of radius for well over 150 years and in our windy climate crowns may become much broken up. First quality planking commands a good price, at sizes from 60 cm diameter at breast height upwards and this will require well over a century if growth averages 4 rings per centimetre (10 rings per inch). To achieve, and retain this sort of steady growth requires trees with ever-expanding crowns. The final crop trees are likely to stand between 12 and 15 metres apart, depending on the species of oak grown – pedunculate needs more room than sessile – and on the soil and climate.

Fine oak is always in demand. Selected acorns, from a tested seed source, grown by a skilled nurseryman into good quality transplants form the foundation for a crop of fine oaks. Thereafter, the forest owners and managers have limited influence. At the forest scale the climate is fixed but at the stand level, especially when the trees are young, the microclimate can be modified by adjacent shelter, or even sparse canopy. Soil can sometimes be improved by drainage, subsoiling or applying deficient nutrients as fertilizer: in later years, by leaf litter from trees in mixture with the oaks.

If a final crop of between 50 trees (14 m apart) and 100 trees (10 m apart) is envisaged, how many should be planted? A spacing of 1.5 x 1.5 m requires over 4000 per hectare; at 2 x 2 m the figure is 2500. All need to be purchased, planted and weeded but (at 2 x 2 m) about 2400 of these plants will be removed in cleanings, or thinnings as cordwood, fencing or lower-grade planking, to leave but the best to maturity. What is more, a pure oak plantation is just as much a monoculture as wall-to-wall Sitka spruce, so many careful oak growers have always planted mixtures in groups or in lines, tending them thereafter to give well-considered results suited to the growing site. Care is needed to avoid a “pyjama stripe” effect from prominent viewpoints!

Simple rules apply. The ideal nurse, or “infill”, will last about half the oak rotation and provide an intermediate financial return; will not outgrow it and will not make a compacted acid litter; in addition, should grey squirrels become active the nurse will be damaged in preference to the oak. Thus hornbeam, lime, alder, sycamore and beech are candidates. Lime outgrows oak but trees removed as thinnings will coppice; alder and sycamore will also grow fast and coppice, but will not last the full course and beech can be too aggressive as well as making a felted, acid litter layer which can deprive the oak of moisture in dry times. Among the conifers Norway spruce is the classic nurse and western red cedar is often better, though less likely to survive into the oaks’ final years. Using a nurse can improve the growing conditions and form of the oaks, can retain better site fertility,

increase the range of habitats, keep the oak stems shaded (and hence free of whiskery epicormic shoots) and also save useful sums in the costs of plants and tending.

British literature on thinning tends to concentrate on "what shall I remove - how much volume will it produce"? When growing fine oaks the boot is on the other foot. What trees am I favouring? How far apart? The aim should be to bring on not only the winners but also candidate replacements, should a potential winner fail at age 80 due to gale damage.

An even rate of growth is of prime importance for producing stable oak timber. This requires a steady increase of crown room so before each thinning, inspection of the chosen trees should show a few fairly small dead branches in the lower crown but a vigorous main canopy. Pure oak is a difficult crop to thin in its later and most important years as this can lead to crown damage. Oak-sized holes are left in the canopy, thus exposing the trunks of the remaining crop to the risk of epicormic shoots (whiskers on the stem) developing due to extra light. All the nurse species discussed earlier are softer trees whose removal will cause minimum damage to retained oaks. Shade-tolerant nurses will be capable of remaining as a trunk-shielding understorey, preferably until after the final oak thinning.

The final thinning is particularly critical as large trees will be removed, yet the chosen final crop individuals are likely to have 25 or more years to grow. At this thinning it is less important to keep the steady growth rate of earlier years. The last 25 years of an oak's growth is all sapwood, around an increasing and valuable heartwood core. Sapwood is of little value to the timber merchant, whose proper interest is in the dark, brown heartwood.

A more detailed report on the ecology of oak and its management written by Peter Savill can be found on the FTT website.

3.5 Use of genetic technologies: molecular characterization of Forest Genetic Resources

There is an increasing emphasis on the use of molecular markers for genetic characterization and tree breeding. Molecular markers can be used in the selection of populations to conserve (e.g. Petit *et al*. 1998) and can also be used in selection of breeding material. This approach is promoted in the EUFORGEN pan-European strategy for genetic conservation of forest trees (de Vries *et al*. 2015). Molecular markers can be used to determine provenance and assess genetic diversity in populations (Nybom *et al.* 2014). Molecular markers have a variety of forms and each can be used to investigate different aspects of a species or a population. For plants there are three target genomes, the mitochondrial, the chloroplast and the nuclear genome. Mitochondrial DNA markers tend not to be used in plants, except for gymnosperms (e.g. Scots pine mitotypes). Chloroplast DNA (cpDNA) markers tend to be conserved and are useful for assessing species distinction and for large-scale or longer-term population dynamics. For example, cpDNA has been used extensively to study the genetic structure of tree populations in Europe (Petit *et al*. 2003). Nuclear markers are more useful for finer scale population analysis and, for example, for paternity tests. Two marker systems that are most frequently used are SSRs (Simple Sequence Repeats) and SNPs (Single Nucleotide Polymorphism). SSRs are small segments of repeat DNA and can be assessed based on the difference in sizes of the repeat number. SNPs are mutations at a single DNA location. SNPs are particularly

useful for cross-lab comparisons as they are based on DNA sequence, which tends to be unambiguous and thus cannot be subjectively inferred in the analysis. SNPs are becoming increasingly available with the increase of DNA technologies and genomic data and are particularly important in looking at variation in coding regions.

The availability of genetic resources for oak

The full genome of oak has been published (Plomion *et al.* 2016) including molecular markers associated with important traits such as bud burst (e.g. Lesur *et al*. 2015). There are also numerous individual-level forest stand studies and provenance trials that have been genetically characterised. Molecular markers could be used to guide breeding programmes and add to information on parentage. Markers could also be used to investigate gen**e**tic diversity and thus genetic potential in a population or set of plus trees for specific traits, such as bud burst or flowering.

3.6 Important points to consider from the Breeding Strategy

The Oak Breeding Strategy was prepared in 2010 by David Boshier of Oxford University and details much additional current knowledge governing oak genetic resources and reproductive biology. It contains much relevant material to guide steps going forward in our improvement programme. Important summary points are given below.

Genetic makeup of oak

- In GB, there are three haplotypes for oak: haplotype 12 found in 98 % of all samples indicated forestation after the last glaciation from the Iberian peninsula; haplotype 11 arising from a post glacial mutation in East Anglia, but also present in eastern Britain; and haplotype 10 found in less than 2 % of samples arising from populations further east (Italy, the Balkans). Most populations are fixed for a single haplotype, although mixed haplotypes were found in the Welsh Marches and parts of Scotland (Cottrell *et al.* 2002; Kelleher *et al*. 2005).
- In Ireland a study by Kelleher *et al.* (2010) has shown a genetic link between Irish oak and those that originate in the Iberian Peninsula refugia. Five haplotypes have been recorded in Ireland but only two dominate – 10 and 12. The few trees with other haplotypes (1, 2, 7 and 11) were recorded in planted woodland and it is likely that they represent stock introduced by landowners or forest managers. Genetic diversity of Irish oak populations was lower than that found in other European populations. A comparative country in terms of size and distance from putative refugia is Denmark and Ireland ranks closely with Denmark in overall diversity (Kelleher *et al.* 2010).

Hybridization of *Quercus robur* and *Q. petraea*

- *Quercus robur* and *Q. petraea* hybridize readily (Rushton 1993) and gene exchange is extensive where they overlap, though the extent of natural hybridization varies greatly (Gardiner 1970).
- Reproduction barriers to prevent hybridization are weak (Bacilieri *et al.* 1996; Manos *et al.* 1999).

Reproduction

- Frost sensitivity of acorn production (in southern England) is highest in early April; later frosts do not lead to loss of crop probably because primary shoots have hardened by then. Low air temperatures can delay development of female inflorescences.
- There is no correlation between flushing date and acorn production.
- Open canopies produce many more acorns. Thinning and consequent crown expansion has the potential to increase acorn production.

Pollen dispersal

- Oak has high potential for long distance pollen dispersal (over 100s of km).
- High variation in flowering phenology at the individual, population and annual levels lead to diversification of the effective pollen cloud received by each tree for a given year.
- The effective number of pollen donors per mother can be high (>15 per tree; Streiff *et al*. 1999).

Frost susceptibility

Frost damage to particular organs is dependent upon flushing stage at time of exposure. Following frost injury, most trees respond by producing new leaves from secondary buds. Southern and south eastern European provenances flush earlier than more northern/western ones and are more susceptible to late spring frosts. Selection and propagation of the latest-flushing trees is suggested to minimize risk of late spring frost damage. However, this conflicts with the desire to select early flushing oak that are more likely to have smaller vessel sizes, a trait under strong genetic control.

Meeting seed demand through plus tree and selection and orchards

In the previous business plan (2007), the oak group identified the need for additional plus trees to meet criteria to address seed orchards on a region of provenance basis. This thinking has moved on, and proposed clonal seed orchard make up has been adjusted in light of more up to date knowledge about climate change and adaptation (see section 4.3 and 5). Splitting orchards by species, and not accepting trees with vessels radius greater than 160 microns will likely require the identification of additional superior trees. However, rather than meeting this need through additional plus tree selections from the wild (which will be very costly, and doubtful of success given an already thorough assessment of the country) already improved material could be sourced from the French breeding programme.

Breeding seedling orchards (BSOs) and clonal seed orchards (CSOs)

The eight BSOs contain oak of both species. To appear on the FRM register, they must be rogued to a single species. Species hybridization can be high, particularly where background levels of external pollen are high as is likely in our BSOs. At year 5 (2007) *Quercus robur* showed greatest height growth at Belmont, Little Wittenham, Newton Rigg, and Sotterley (mainly the more southern and eastern orchards) and *Q. petraea* grew best at Dalkeith, Shakenhurst, Rathluirc and Bwlchgwynt (the more northern and western sites, with the exception of Newton Rigg).

Clonal orchards are generally more expensive to establish than seedling orchards. However the time factor in collecting acorns alters this balance. Unthinned seedling and clonal orchards offer similar

levels of gain but a delay in production from seedling orchards can be expected. Clonal orchards should give a more predictable supply of improved seed more quickly; this is increasingly important for species with long generation times, such as oak. Although initial genetic gains will be comparable, later thinning of clonal orchards can raise the predicted genetic gain above that of thinned BSOs.

Without progeny test information on parent trees there is no basis for rogueing clonal orchards. Progeny performance can be properly evaluated in seedling orchards designed for the purpose. Selection criteria will centre on growth rate and form, but should encompass leaf flushing and the degree to which this is genetically controlled as it is important both for production of trees with superior form and to avoid shake. Assessment of the same families across the different BSOs can guide the extent of genetic control vs plasticity in this trait and their stability with climate change. Of particular interest will be to see how well the French and Dutch material integrates. In some species although there are large differences in flushing time, this still all occurs within the time frame within which last spring frosts occur, such that all or most of the material is affected by frost.

4. Progress to Date

4.1 Seed Stands

Seed stands – stands of trees that are managed to maximise seed production through thinning and clearing ground vegetation – represent a quick and inexpensive method of obtaining seed of improved genetic quality until more intensely selected material is available from seed orchards. Seed stands can be either source identified, or source selected in which case they will have been inspected by the Forestry Commission, and accepted as selected according to regulations.

On the National Register of Approved Basic Material for Great Britain, there are 108 registered seed stands of oak; 64 for *Q. petraea* and 44 for *Q. robur*. Twenty one of the 64 sessile stands are source selected with the vast majority of these from region 40. For pedunculate oak, 32 of the 44 stands are selected, distributed evenly across Britain. Ireland has a total of 94 registered oak seed stands (Fennessy *et al.* 2012), split equally across the two species (Table1). Many of these stands in both countries are not managed – thinned to produce healthy crowns – and seed is not collected, often due to poor access and lack of dedicated management.

An audit of selected seed stands was carried out by Forestart in 2014 (Forestart 2014). They noted sessile oak crops less reliably than pedunculate oak and a lack of registered selected seed stands in the north and west of GB is problematic. Although seed stands in region 30 (see Figure 1 and Table 1) are few, they could be expanded to meet demand. Some stands were struggling because of undergrowth issues, although a few Forestry Commission stands had recently been brought back in to active management, and could almost meet demand if opened up to the private sector. However, wild boar remain an issue in many areas. For pedunculate oak, the report highlights a lack in stands in Scotland and region 30 (see Table 1).

Table 1. Summary of seed stands on the register of approved basic material in Great Britain and Ireland in 2016. Numbers in brackets are those in the source selected category.

	Quercus robur	*Quercus petraea*	Total
Region 10	5 (0)	28 (2)	**33 (2)**
Region 20	4 (3)	12 (1)	**16 (4)**
Region 30	3 (3)	5 (2)	**8 (5)**
Region 40	32 (28)	19 (17)	**51 (45)**
Ireland	47	47	**94**
Total	**91**	**111**	**202**

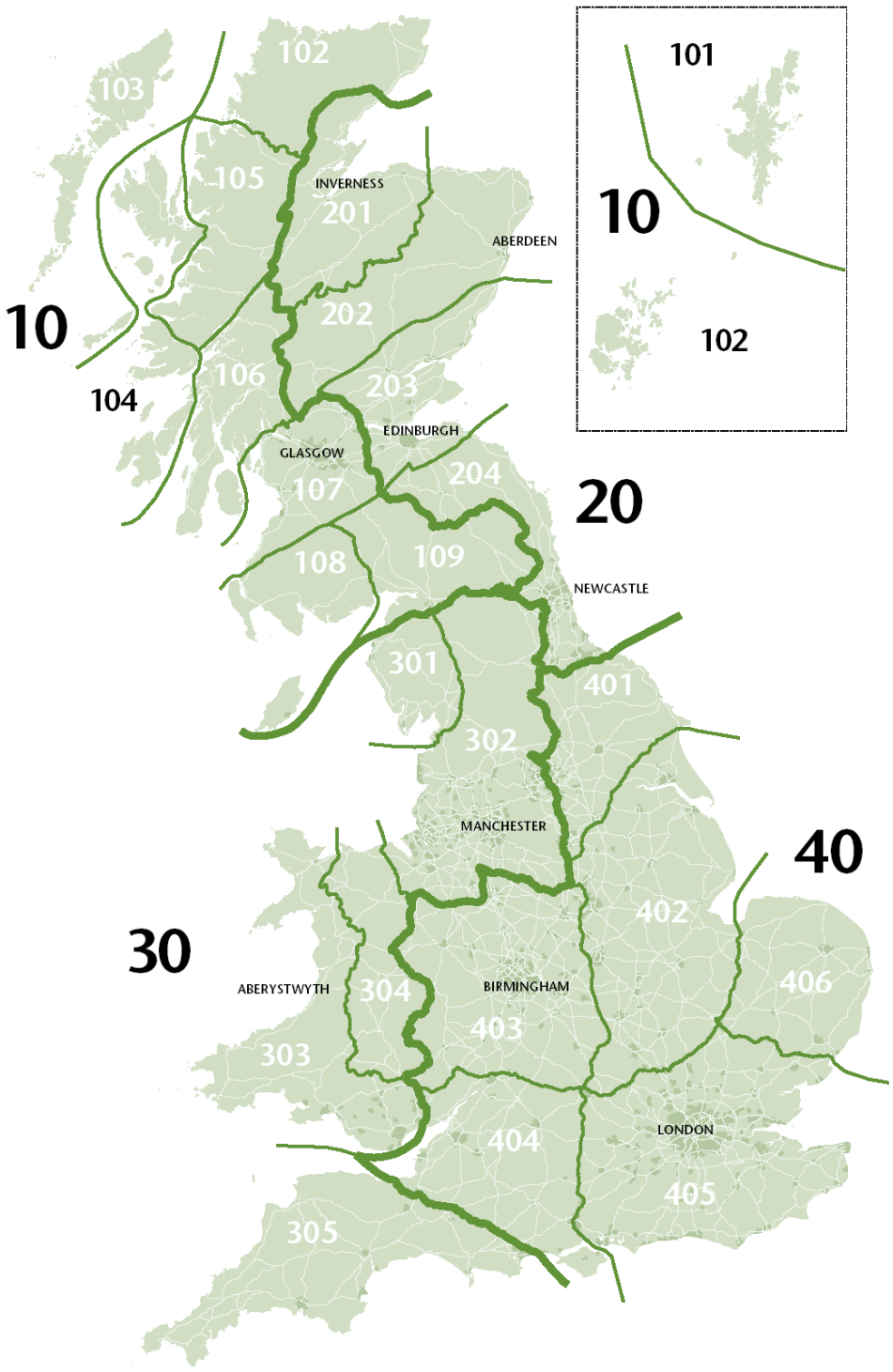

Figure 1. Map of regions of provenance and their associated seed zones for Great Britain (Herbert *et al*. 1999). Regions of provenance are identified by two-digit code; seed zones by a three-digit code. Ireland is classified as one region of provenance.

4.2 Plus Tree Identification

Using these seed stands as a starting point, phenotypically superior trees (called Plus Trees) were selected in the 1990s in both Great Britain and Ireland (Table 2).

In total there are 193 GB plus trees mainly selected between 1997 and 1999 by Jason Hubert. These trees were identified at the species level, and increment cores taken and vessel size assessed. Additional selection made between 2005 – 2007 by East Malling Research, often did not give a species and increment cores were not taken.

Table 2. Numbers of plus trees selected by species and region/ country by FTT members.

	Quercus robur	*Quercus petraea*	Hybrids	Total
Region 10	6	1	0	**7**
Region 20	14	5	0	**19**
Region 30	10	8	0	**18**
Region 40	88	53	8	**149**
Ireland	7	13	0	**20**
France	5	37	0	**42**
Netherlands	24	0	0	**24**
Total	**154**	**117**	**8**	**279**

From 1990 to 1994, 102 oak trees were selected in Ireland, under the EU ÉCLAIR programme (Table 2). In 1999 20 oak plus trees were selected in Ireland by FTT, but some of these were included in the earlier selections. Since 2015, trees are being revisited to take cores to assess vessel size and to ascertain species. However, it is usually not possible to relocate the original tree. Where no clone of a plus tree exists, and no original plus tree can be found, new selections are being made to ensure good geographic coverage of the oak resource in Ireland. Fifty of the original ÉCLAIR plus trees were revisited in 2015 and 2016 (Table 3). Where the original tree was felled or it was not possible to relocate, a new tree of similar quality was substituted.

For all recently collected (since 2015) increment cores, vessel sizes were determined by Dr Annette Harte in the Civil Engineering Department, National University of Ireland in Galway.

Table 3. Numbers of plus trees selected in Ireland from the 1990s and revisited from 2015 onwards.

	Quercus robur	*Quercus petraea*	Hybrids/ unknown
Original ÉCLAIR 1990s			102
New selections	23	25	2

Scions were collected from some of the trees from the ÉCLAIR programme, and grafted trees are held in clonal archives at Newtonmountkennedy in Co. Wicklow (19 trees) and at Kilmacurragh, also in Co. Wicklow (46 trees). A further archive at Kilmacurragh houses 43 trees of GB, French and Dutch origin.

Shake is a serious defect of timber which causes splits in the standing tree, and is a notable problem for oak. A correlation with vessel size has been reported, with those trees with vessels with a radius greater than 160 µm likely to be more prone to shake (Savill and Mather 1990). Therefore, as a further criterion for plus tree selection, increment cores were taken from trees selected by Future Trees Trust for assessment of vessel size. It had previously been decided to exclude trees with vessels greater than 160 µm radii from the breeding programme. However, this has an impact on the clonal seed orchards (section 3.3) as approximately half the selected plus trees fail on this criterion.

Table 4. Numbers of trees by species and by country that pass/ fail the 160 µm radius limit for association with shake. This table does not include ECLAIR selections in Ireland.

	GB	Ireland	France	Netherlands
Robur pass	49	5	5	5
Robur fail	40	2	0	19
Robur unknown	28	0	0	-
Petraea pass	27	12	30	-
Petraea fail	30	1	7	-
Petraea unknown	10	-	-	-
Hybrids pass	2	-	-	-
Hybrids fail	5	-	-	-
Hybrids unknown	1	-	-	-

Table 5. Numbers of trees in Great Britain by species and region of provenance that pass/ fail the 160 µm radius limit for association with shake.

	10	20	30	40
Robur pass	4	9	1	35
Robur fail	1	5	4	30
Robur unknown	1	-	4	23
Petraea pass	-	3	5	19
Petraea fail	1	2	1	26
Petraea unknown	-	-	2	8
Hybrids pass	-	-	-	2
Hybrids fail	-	-	-	5
Hybrids unknown	-	-	-	1

4.3 Clonal archives and seed orchards

Many, but by no means all, of the selected plus trees and their progeny are deployed in a number of clonal seed orchards or seedling orchards which also function as progeny trials. In 2003 we established eight breeding seedling orchards (BSOs – progeny trials, that once rogued will function as seed producing orchards) which comprised half sib families from 62 of the selected plus trees. However, seed production from these in any useful quantity is not expected until 2040 at the

earliest. We therefore decided also to establish ten clonal seed orchards to help meet the seed demand for oak.

Micropropagation or multiplication by grafting relies solely on phenotypic selection and removes the possibility for further genetic gains that can be realised through sexual reproduction and progeny trials, but can rapidly provide good planting stock. Due to the low seed output of oak per hectare, some form of scaling up will be necessary to disseminate the improved material and, when improved seed is available, large scale methods of vegetative propagation will be needed.

There are three clonal archives in Ireland, two with trees of Irish origin and a third with trees of GB origin. In Britain, there is a well-managed clonal hedge at Sotterley and a few trees in poor condition at Little Wittenham. There is also a clonal archive at Glencorse, near Roslin comprising (up to) three ramets of 78 plus trees from across the geographic range.

There are currently no clonal seed orchards for oak in Ireland or Britain although Forestart have a small number of grafted oak, of mixed species.

4.4 Seedling seed orchards and progeny trials

Progeny trials assess the parental genotype by study of its progeny under controlled conditions. The aim is usually to determine the true breeding value of a tree, especially females, which are used extensively for the propagation of the best germplasm. An open-pollinated progeny test is performed by pollinating female flowers with an unknown number of males to produce many progenies in different environments and over a long time period to minimize the impacts of season, management, and environment in breeding value estimation. The average performance of the offspring is then found, giving a measure of the mother tree's respective value to the breeder.

Over three years (2000 – 2002) acorns were collected from 66 of the plus trees and raised at Forest Research's Northern Research Station at Roslin, Edinburgh. A series of eight breeding seedling orchards (combining testing and production) were established in 2003 (Table 6). These have been assessed for growth several times, most recently in 2014 (11 years old). Budburst observations were carried out at four sites in 2014. Two papers have arisen from the 11 year data – one on phenology and another on family performance (currently both in preparation).

Several of the sites have specific issues: at Dalkeith, a supposed insect pest attack detrimental to form has been so severe that the entire site was stumped in 2013, and was singled in 2016. At Newton Rigg, vole damage was so severe that the site was consolidated from 63 replicates to 40 replicates in 2008, but further problems have arisen as to certainty of family identity. Additionally, the trees have been pruned at this site. At Bwlchgwynt, the trees are showing a similar stag headed appearance to those at Dalkeith prior to stumping, and this is attributed to its close proximity to the coast and salt wind damage. In spring 2016, a subset of eight replicates was stumped to ascertain whether this may be a way out of this problem. At Shakenhurst, the trees have grown so well, that they are twice as tall as those at the next best site (in terms of height growth), which necessitated thinning of a third of the trees in spring 2016. Sotterley, Little Wittenham, Rathluirc and Belmont are in an acceptable condition, and will not require thinning until 2017-2020.

Table 6. Site details of eight breeding seedling orchards in Britain and Ireland.

Site	County	Grid Ref	Families	Reps	Trees	Area (ha)
Sotterley	Suffolk	TM 427861	61	50	3,050	1.22
Little Wittenham	Oxfordshire	SU 553936	56	39	2,184	0.88
Shakenhurst	Worcestershire	SO 684734	21	100	2,100	0.84
Belmont	Kent	TQ 970571	34	70	2,380	0.95
Newton Rigg	Cumbria	NY 349531	40	63	2,520	1.01
Dalkeith	Midlothian	NT 368695	31	85	2,635	1.05
Bwlchgwynt	Carmarthenshire	SN 281287	44	52	2,288	0.92
Rathluirc	Cork	52° 19'N 8°	46	48	2,208	0.88

These trials contain oaks of both species. Their aim is to evaluate breeding values, and maximise genetic gains upon rogueing for seed production. Those orchards that have enough families of a single species to maintain adequate levels of genetic diversity will be rogued to a single species, and the acorns placed on the open market.

4.5 Other related research

A number of research projects related to growing high quality oak have been commissioned or produced by partners, and reports for many of them can be found on the FTT website: www.futuretrees.org

- Get your seed stands registered. 2006
- Oak Breeding Seedling Orchards: Jo Clark 2007
- The importance of seed stands in broadleaved forestry: Fennessy *et al*. 2007.
- Oak: fine timber in 100 years. Jean Lemaire, translated from the French by Bede Howell
- Acoustic Velocity Measurements of Oak. Do these indicate mean vessel size? (Price and Savill 2013)
- Shake in oak: an evidence review. (Price 2013)
- The use of molecular markers and morphological leaf traits for species identification in the Future Trees Trust oak BSOs and plus tree collections. David Boshier and Graham Muir 2014
- Grafting Oak Plus Trees. Gerry Douglas and John McNamara 2014
- Juvenile Mature Correlations in Irish Oak Provenance Trials. Stuart Kennedy 2015
- Oak Vessel Screening report. Steve Gregory 2016
- Acorn Storage interim Report. Shelagh McCartan 2016
- Vegetative Propagation of oak: what are the best options? Rick Worrell 2016
- A review of oak and chestnut seed stands (Forestart 2014)
- A method of inducing early flowering in oak. AFBI
- Oak Monograph. Peter Savill 2011
- The timing of budburst in oak, relating to genetics and shake. Clark in prep
- Eleven year results from progeny trials. Clark in prep.

5. Aims and Objectives

5.1 The FTT Strategy

The Future Trees Trust strategy document *A future With Broadleaved Trees* sets out the Objectives and Targets for Future Trees Trust as a whole (see box 1). These objectives and targets have been used by the oak group to guide us in the future development of the programme.

Box 1: Future Trees Trust Strategy 2013-2025: Objectives and Targets.

Future Trees Trust Strategy – Objectives and Targets

Objective 1: Delivering improved broadleaved trees through research

Target 1: Increase the number of species selected and bred for improved productivity and maintenance of genetic diversity

Target 2: Increase the amount of improved seed available for a range of broadleaved species (both native and introduced) by strengthening existing research programmes on major species

Target 3: Co-ordinate and establish greater awareness of shared research priorities, building strong networks of stakeholders from the many woodland sectors

Objective 2: Raising awareness of the benefits of using improved broadleaved trees

Target 4: Raise awareness of the benefits of using improved broadleaved trees and better woodland management

Target 5: Increase the numbers and quality of management of seed stands

Target 6: Promote awareness of the existing registers of improved material and seed stands as an interim measure prior to improve seed and trees becoming widely available

Objective 3: Establishing a policy framework that encourages planting of improved broadleaved trees

Target 7: Identify and undertake the research and implement the policy measures needed to ensure that the most appropriate seed sources are used in all new broadleaved woodland planting

Target 8: Promote the need to review the current native seed zone and provenance specifications and future relevant policies, to reinforce different woodland and forestry objectives

Target 9: Influence all those with a remit to plant trees in whatever setting to actively encourage and incentivise where appropriate the planting of improved material.

5.2 Oak Group Objectives

The three principle objectives of the oak breeding programme, stated earlier, but repeated here for individual examination of Objectives and Targets, are:

1. To secure, conserve and utilise key genetic resources of selected oak plus trees and registered seed stands for production of improved forest reproductive material and to work towards the provision of an adequate supply of this improved material to commercial forest owners in Britain and Ireland.

2. Enhance and increase the volume of recoverable high quality oak timber per hectare for the forest owner by using genetically improved reproductive material accompanied by promoting best silvicultural practices for oak production. Increase the value and quality of the oak timber produced.

3. Provide information and support on best oak seed sources to the nursery trade and other key players including forest and woodland owners.

FTT Objective 1: Delivering improved broadleaved trees through research

1. Oak Group Aim 1: Select the best plus trees

Additional plus trees must be selected (or increase our cut off point for inclusion based on vessel size) to meet genetic diversity criteria of a minimum of 50 genotypes per clonal seed orchard. It may be possible to increase the number of French and Dutch plus trees by purchasing trees from French and Dutch breeding programmes, thereby reducing the costs of finding additional plus trees in the wild. This has the added benefit of a certain degree of improvement already identified, and will help address the balance of near continental material required to future proof our planned orchards.

Target 1. Revisit the remaining plus trees in Ireland to determine species and take cores for assessment of vessel size.

Target 2. Identify additional plus trees to meet genetic diversity criteria in the clonal seed orchards including from the near continent.

Target 3. Screen all trees for vessel size and determine which trees to include in orchards.

Target 4. Investigate shake in trees when felled, by taking cores at time of felling and relating vessel size to whether the felled tree is shaken.

2. Oak Group Aim 2: Establish clonal seed orchards (CSOs)

Seed orchards must contain only one species if acorns arising from them are to be marketed. Ireland is considered one region of provenance (both the Republic and Northern Ireland) and due to the long history of movement of oak, will allow trees from all regions that FTT have selected plus trees

from, including French and Dutch material. We will establish two orchards for each species, one in the north and one in the south.

Britain is split in to four regions of provenance (Figure 1). Although it will not meet seed demand, as a first step, we will establish three orchards for each species, with the aim of future proofing acorn production for changes in climate, rather than addressing regions of provenance solely. We will follow Forestry Commission recommendations, of sourcing material from 2° degrees latitude south of planting site. Thus, orchards planned for Scotland will include material from England, and orchards planned for England will include near continental material. Table 7 shows the breakdown of the origin of material that will be represented in each planned orchard.

Table 7. Location and composition of ten proposed clonal seed orchards for oak species in Britain and Ireland.

Orchard	Species	Origin of clones	Potential orchard host
IRELAND			
North	*robur*	IRE, GB, NLD, FRA	Forest Service Northern Ireland
North	*petraea*	IRE, GB, NLD, FRA	Forest Service Northern Ireland
South	*robur*	IRE, GB, NLD, FRA	Private
South	*petraea*	IRE, GB, NLD, FRA	Private, Co. Waterford
BRITAIN			
North	*robur*	RoP 10, 20, 30, 40	?
North	*petraea*	RoP 10, 20, 30, 40	?
South	*robur*	RoP 40 and FRA	Woodland Trust, National Forest
South	*petraea*	RoP 40 and FRA	Maelor Nursery, Shropshire
West	*robur*	FRA, NLD, IRE, RoP 30 and SZ 403	Private, Kent
West	*petraea*	FRA, NLD, IRE, RoP 30 and SZ 403	Whitfield Estate, Hereford

Table 8 shows how many trees have already been selected (and passed the vessel screening process) that could be included in each orchard, and the number remaining to be screened.

Table 8. Number of plus trees selected with mean vessel size less than 160 µm. The last two rows are the trees that have been selected but not screened for vessel size.

	IRE North	IRE south	UK North	UK South	UK west
Robur	74	74	52	42	21
petraea	61	61	27	41	47
robur to screen	34	34	29	23	9
petraea to screen	21	21	10	16	17

NB. Individual plus trees are often represented in more than one orchard but they only need to be screened once. Trees to screen are given in each orchard, to show the total number that *may* be included in that orchard, should all tree pass screening. The total to be screened is 55.

Each orchard will comprise a minimum of 50 genotypes, and 6 to 10 replicates (ramets) per genotype. Therefore each orchard will have approximately 500 trees, at 6 x 7 m spacing. This is 238 trees /ha so a minimum requirement of at least 2 ha (476 trees) is required per orchard. Table 8 also illustrates the need for additional plus tree selection, particularly for *Q. robur* in the west, and *Q. petraea* in the north.

In January 2016, scion material was collected from clonal archives in GB and sent to Matthews nursery in Herefordshire for grafting to commence clonal production for the ten CSOs planned. Grafting from hedge material that has been rejuvenated is relatively straightforward, and grafting success was in the region of 70 %. However, grafting using material from mature plus trees is hard because new growth is very short – often only 1 cm a year – and we have typically achieved success rates of 10 – 15 %.

Target 5: Identify suitable sites for 10 clonal seed orchards.

Target 6: Collect scions from clonal hedges for grafting.

Target 7: Collect scions using climbers from plus trees in the wild.

Target 8: Establish 10 clonal seed orchards.

3. Oak Group Aim 3: Establish clonal archives

For conservation purposes, every plus tree should be secured in clonal archives, one in Ireland and one in GB. Ideally, these should comprise 3 ramets of every selection, a total of 380 trees, (278 FTT selections, and *c.*100 Irish selections) equating to 1140 trees per archive. However, propagating oak is difficult with some accessions proving almost impossible to graft while others take readily.

Archives will be established in rows 4 m apart with trees 1-2 m apart within row.

Target 9: Identify sites suitable for oak clonal archives in Britain and Ireland, and secure all plus tree selections.

Target 10: Keep abreast on propagation techniques, and take advantage of new technologies as they become successful e.g. tissue culture of oak as a means of mass propagation.

4. Oak Group Aim 4: Test the progeny through progeny trials (BSOs)

Sixty two half sib families (seed collection from 62 parent trees, of unknown pollen fathers) are being tested in the BSOs. Five and eleven year performance data have been collected; a final assessment at about year 20 will be required prior to rogueing and calculation of breeding values. The remaining plus trees are not currently being tested.

A second series of progeny trials could be undertaken, on a species basis, to evaluate all selected plus trees to obtain breeding values. This could be done by revisiting the plus tree in situ, or waiting

until the CSOs produce seed and then test the progeny (Target 13). However, this is very time consuming and therefore requires considerable financial investment. An alternative method to evaluate the plus trees could be to establish a series of trials to test the progeny from open pollination of the CSOs across a range of sites (Target 14)

Target 11: Manage the BSOs until final assessments around year 20, prior to calculating breeding values for traits of interest.

Target 12: Carry out final assessments in the existing BSOs at age 18-20 (2021-2023) and rogue the orchards, and register them as tested on the FRM register.

Target 13: Establish single species progeny trials to test the remaining untested plus trees; *or*

Target 14: Test offspring of the CSOs through a series of trials of progeny arising from open pollination of the CSOs across a range of oak sites.

5. Oak Group Aim 5: Resistance to pests and diseases

To ensure that resistance to current and possible future pests and diseases is considered as an integral part of breeding and seed supply activities. In particular, consideration will be given to:

- Oak processionary moth
- Powdery mildew
- Acute oak decline
- Squirrels

We recognise the importance of these issues but currently don't have the knowledge or resources to develop research in these areas. We promote planting stock with a broad genetic base to enable adaptability within populations. However, as new research is carried out we will keep abreast of it, and apply it as appropriate, for example, marker aided selection to screen for tolerance to powdery mildew.

FTT Objective 2 Raising awareness of the benefits of using broadleaved trees

6. Oak Group Aim 7: Seed supply (from registered seed stands)

A small proportion of acorns used by the nursery trade come from British and Irish oak, and only a small proportion of these come from registered seed stands. With forest health rising up the political agenda, it is highlighting the need to source home-grown planting stock derived from British and Irish trees, limiting foreign imports (and thus exposure to foreign pests and diseases).

Target 15: Select ten seed stands for each species on the register, and promote their management for seed production.

Target 16: Lobby government to provide central funds to support seed stand management.

Target 17: Assess which seed stands should be removed from the registers in both countries.

7. Oak Group Aim 7: Demonstration

The benefits of planting improved material should be established to illustrate the differences between the qualities of *source identified*, *source selected* and *qualified* material through a series of demonstration plots.

Target 18: Establish demonstration plots for oak with various categories of FRM and nursery standards.

8. Oak Group Aim 8: Promotion

Promote the use of broadleaved trees and oak in particular for timber production, and work with others to further this.

Target 18: Promote the use of seed stands and good silviculture.

FTT Objective 3. Establishing a policy framework that encourages planting of improved broadleaved trees

9. Oak Group Aim 9: Regulation

In many EU countries there is specialist grant support for using improved material as in the Republic of Ireland. Currently, in the UK, there is no requirement to use improved material where it exists.

Target 19: To work with the Forestry Commission (GB) and the Forest Service (IRE) policy personnel to ensure that oak planted for timber production in Britain and Ireland is subject to well-grounded and pragmatic rules for resilience in light of novel pests and diseases, and climate change adaptability, and to design breeding activity to fit with those rules.

Target 20: lobby the grant awarding bodies to support the use of improved material.

6. Funding

There are many targets within this business plan, and not all are possible immediately. We will address funding requirements on a target by target basis.

Currently (November 2016) we are completing the screening of all plus trees for vessel size, collecting scion wood from the plus trees from either hedges or in situ to establish two clonal archives (one each in Ireland and England) and grafts for six CSOs – one to be located in Ireland and two in England for each species, although ten CSOs are planned in total. This includes two archives each of 1014 plants (3 ramets each of 338 accessions) which will house all British and Irish selections; and six CSOs which will each house approximately 500 trees of various accessions and ramets of each giving a total of approximately 5,000 grafted oak. The final planned orchards (two more for Ireland, and two for Northern England/ Scotland) will be addressed at a later date.

A detailed breakdown of the costs of collecting scion wood from the remaining plus trees not yet secured using climbers, and of producing plants for this resource, is presented here. It does not include costs associated with orchard establishment. Costs are based on 50 Irish trees climbed over two years, and 104 GB trees climbed over four years (25/26 trees a year from each country).

Item	Unit cost	Quantity	Anticipated start / end date	Total
1. Identify and visit oak plus trees to take cores			UK – completed March 2016 Ireland – underway, complete 2017	Already funded
2. Assess vessel size			UK – completed September 2016 Ireland – underway, complete 2017	Already funded
3. Collect graftwood from hedges at NRS, Sotterley and Little Wittenham 2016				
a. Collect graftwood				already funded
b. Grafting	£14.00 per successful graft	368	January 2016	£5,152
c. Pot up and grow on for a year	£8.00	210	January 2017	£1,680
(a included milage T&S and postage, already done)				
TOTAL				**£6,832**
4. Collect graftwood from hedges at NRS and Sotterley 2017				
a. Collect graftwood	£250	3	January 2017	£750
b. mileage to Sotterley	£0.45	450	January 2017	£200
c. postage of scions from Sotterley and NRS	£25	2	January 2017	£50
d. Grafting	£14.00 per successful graft	650	January 2017	£9,100
e. Pot up and grow on for a year	£8.00	550	January 2018	£4,400
TOTAL				**£14,500**
5. Graft-wood collection from 104 UK trees using climbers	£300/ day two man team		Will be undertaken in January 2017, January 2018, January 2019, January 2020 (spread over 4 years)	
a. Planning (contacting estates, allocating accessions, etc)	£250	5 days x 4 years	December 2016, 17, 18, 19	£5,000
b. 10 days climbing each year	£300	10 x 4	January 2017, 2018, 2019, 2020	£12,000
c. Posting of scions	£25	2 x 4	posted each week after climbing	£200
d. Subsistence and expenses	£100 pppn	20 x 4	January 2017, 2018, 2019, 2020	£8,000
e. Mileage	£0.45	1000 x 4	January 2017, 2018, 2019, 2020	£1,800
TOTAL				**£27,000**

Item	Unit cost	Quantity	Anticipated start / end date	Total
6. Graft-wood collection of 50 Irish trees using climbers	£300 – per day		Will be undertaken in January 2016, January 2017 (spread over two years).	
a. Planning	£250	5 days x 2 years	December 2016	£2,500
b. climbing	£300	10 x 2	January 2017, January 2018	£6,000
c. Posting of scions	£25	2 x 2	posted each week after climbing	£100
d. subsistence	£100 pppn	20 x 2	January 2017, January 2018	£4,000
e. mileage	£0.45	1000 x 2	January 2017, January 2018	£900
TOTAL				**£13,500**
7. Grafting of UK plus trees				
a. grafting of 104 accessions	£14 per successful graft	3900	January 2017 - January 2020	£54,600
b. growing on for a year	£8	3900	January 2018 - January 2021	£31,200
Total				**£85,800**
8. Grafting of Irish plus trees				
a. grafting of 50 accessions	£14 per successful graft	900	January 2017, January 2018	£12,600
b. growing on for a year	£8	900	January 2018, January 2019	£7,200
TOTAL				**£19,800**
Sub total				**£167,432**
VAT				**£33,486**
TOTAL				**£200,918**

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