Forestry Commission
231 Corstorphine Road
Edinburgh
EH12 7AT
www.forestry.gov.uk

Choosing Provenance in Broadleaved Trees

INFORMATION NOTE

BY JASON HUBERT AND EDWARD CUNDALL

MAY 2006

SUMMARY

This Information Note reviews evidence from trials and provides recommendations and advice to growers seeking to select the best broadleaved provenances for British conditions. Seed lots of native broadleaved species collected in eastern continental Europe should not be planted in Great Britain (GB) unless there is good evidence that such material has performed well over a rotation. Transfering planting material from north to south (of the order of hundreds of kilometres) within GB will generally lead to a loss of vigour compared with using locally sourced material. Transfering material similar distances from south to north will generally lead to increased early vigour, when compared with using locally sourced material. However there may be problems regarding frost-hardiness and reaction to any severe climatic events that may occur in the future. Care should be taken to match the elevation of the provenance with the elevation of the planting site. This becomes of increasing importance the further north within GB the planting site is located and once elevations greater than 300 m are considered. Using seed from a *selected* stand, as defined under the Forest Reproductive Material Regulations, will usually give rise to more productive planting of better form and faster initial growth, compared with using seed from the lower category of *source identified* material. Further provenance trials are planned which will address the degree of local adaptation.

INTRODUCTION

Broadleaved trees now represent the majority of new plantings in Great Britain. In the five-year period 1999 to 2004, a total of 55 700 ha, or 71%, of new planting was of broadleaved species (Forestry Commission, 2004a). Such tree planting may be for timber production or it may have other objectives, such as the restoration of native woodlands, the creation of new wildlife habitats, conservation, landscape enhancement or to provide recreation opportunities. The recommendations given in this Note are mainly for the grower who has the economic goal of timber production amongst their objectives for woodland establishment. However, the general principle of matching a suitable, well-adapted provenance to a site is of equal importance for all other objectives – hence some 'non-timber' species have been included where there is information. Many broadleaved trees have been planted over recent decades with relatively little attention being paid to the provenance or origin of the seed used. Yet planting the incorrect provenance can result in the grower struggling with establishment over many years and, in some cases, total failure of the planting stock (Figure 1).

Origin and provenance are synonymous in the case of a native species that has naturally regenerated on a site. For an exotic species planted in GB, the provenance will be British, but its origin will be the location in its native range from where the seed was first collected.

Origin and provenance

Origin: the geographic locality within the natural range of a species where the parent seed source or its wild ancestors grew.

Provenance: the geographic locality of a stand of trees from where the seed was collected.

Figure 1

Birch seedlings of Norwegian and French provenance raised in the same nursery showing the importance of provenance for determining bud burst.

The Helsinki Declaration (1993) states that, for the sustainable management of forests in Europe, native species and local provenances should be preferred where appropriate and this recommendation has been included in *The UK Forestry Standard* (Forestry Commission, 2004b).

The importance attached to the use of local provenances of native species when planting semi-natural and new native woodlands assumes that local tree populations have become adapted over time to the range of climatic and soil conditions in the place in which they are growing. Herbert *et al.* (1999) provide a framework for sourcing appropriate material of native species where local genetic conservation issues arise by defining a system of 24 native seed zones (see Figure 2). These zones form a sub-division of the four regions of provenance (ROP) into which GB is divided under the Forest Reproductive Material Regulations (Statutory Instruments, 2002). The delineation of the ROPs assumes that broad similarities in geoclimatic and ecological factors will occur within regions but contrast between them. Since the recommendations in this Note apply primarily to planting for timber production, rather than the creation of new native woodlands with a conservation emphasis, reference is made to the four main regions of provenance rather than the native seed zones. However, it is recognised that there will be situations in which native seed zonation may need to be taken into account when choosing planting stock.

The GB has a markedly oceanic climate compared with much of continental Europe and it is important to use suitably adapted planting material. However, a complicating factor is global climate change. The climate of Great Britain has recently been warming at a rate of between 0.1 and 0.2°C per decade and warming is likely to be in the range of 0.1 and 0.3°C per decade during this century (e.g. Broadmeadow, 2002; Broadmeadow and Ray, 2005). A balance may have to be struck between the use of planting material which is assumed to be adapted to past or current local climatic conditions, and material that will be better adapted to future conditions. For example, more southerly provenances are likely to be better adapted to the hotter, dryer summers that are predicted, but also flush earlier and will thus be more prone to spring frost damage in extreme years. Extreme climatic events, which may occur only once in 50 years, can be more important for provenance selection than the average annual climate. This is discussed in more detail in this Note for the exotic frost sensitive species of *Nothofagus* and *Eucalyptus*, but may also be a consideration in choice of provenance for native species.

In GB, the results of extensive provenance testing of commercial conifers by Forest Research over many decades have guided seed choice for commercial planting (e.g. Lines, 1987). The number of broadleaved species trials has been much fewer, but some carefully designed and well-replicated trials of ash (*Fraxinus excelsior*), birch (*Betula pendula*), oak (*Quercus robur* and *Q. petraea*), sycamore (*Acer pseudoplatanus*), red oak (*Q. rubra*) and beech (*Fagus sylvatica*) have been established by Forest Research since 1990. The results of earlier broadleaved species trials were summarised by Worrell (1992). Other trials for which experimental data are available for GB include aspen (*Populus tremula*), willow (*Salix* spp.), poplar (*Populus* spp.), eucalypts (*Eucalyptus* spp.), and the southern beeches (*Nothofagus obliqua* and *N. procera*).

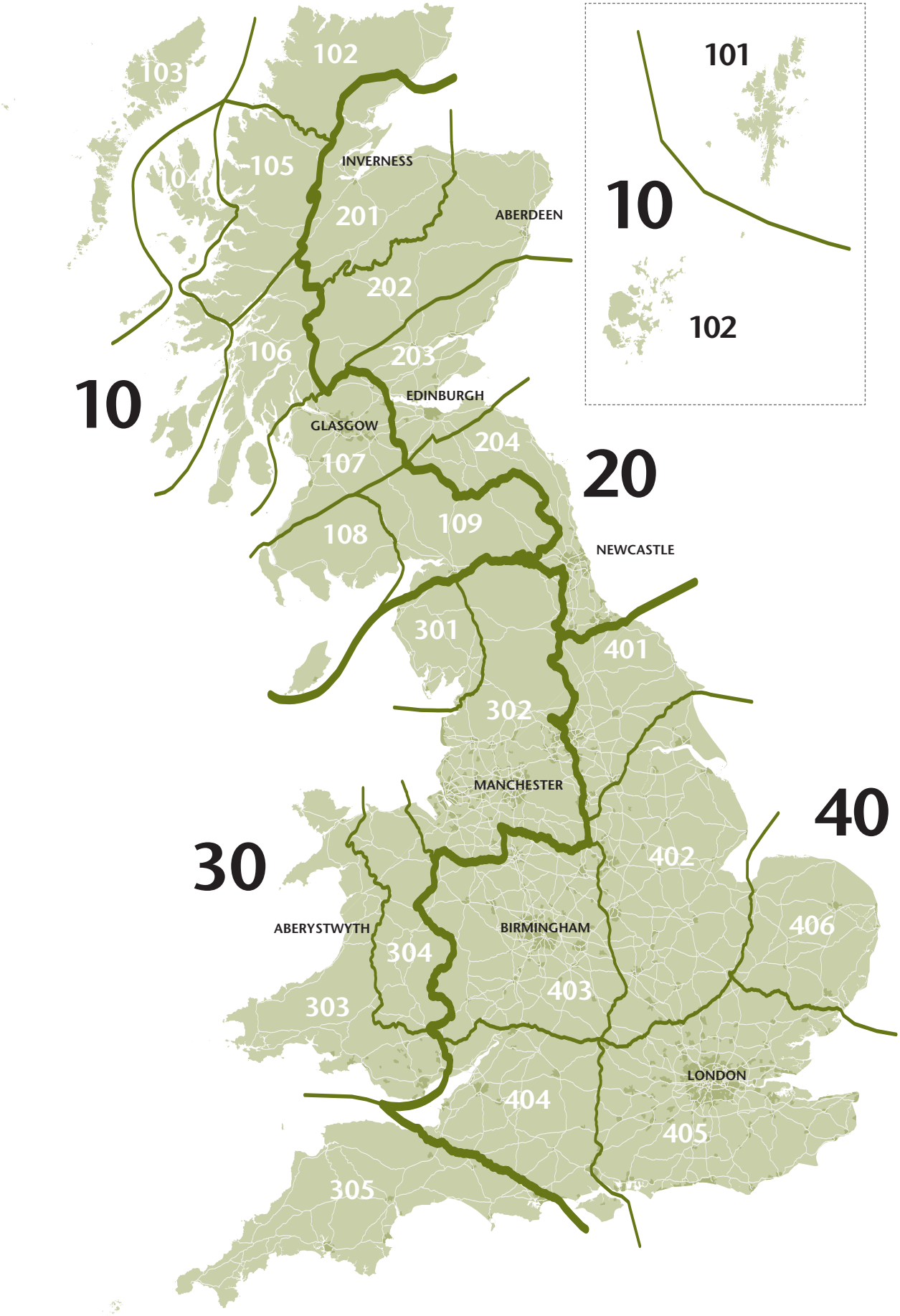
The interpretation of experimental results presents a number of difficulties for the following reasons:

- Only a selection of all potential GB sources appear in the trials planted to date. Those present are drawn from both *selected* stands, i.e. registered seed stands which are phenotypically superior, and the *source-identified* categories, of known origin but no particular phenotypic quality[1]. For a number of species (oak in particular) the provenances used may represent only a small proportion of the *selected* sources available. Statements on the early performance of these limited sources could bias the information available on the performance of GB sources in general. However, those tested can also be interpreted as representative material for their categories.

- Different species have different reproductive, dispersal and ecological strategies and hence the scale of local adaptation and the potential for individual adaptability are also likely to be different. These different patterns of genetic variation between broadleaved species make generalisations beyond the species or genus level difficult and ideally recommendations should only be considered at the species level.

[1]Selected and source-identified are defined by the Forest Reproductive Materials regulations (Statutory Instruments, 2002). See Samuel (2003) for more information.

Figure 2 Regions of provenance (ROP) and native seed-zones in Great Britain.



PROVENANCE CHOICES FOR DIFFERENT SPECIES

Pedunculate oak (*Quercus robur*) and sessile oak (*Q. petraea*)

The choice of pedunculate or sessile oak, or a mixture, can be guided by Ecological Site Classification (Pyatt *et al.*, 2001; Ray, 2001) and Table 17.2 in Evans (1984) together with a knowledge of local history.

Two series of provenance trials of mostly sessile oak were established at a range of sites in 1990 and 1992, the results of which are discussed more fully by Hubert (2005). In these trials GB *selected* seed stands have demonstrated above average vigour at most sites in England and Wales. Twelve years after planting the *selected* provenances were 1.5–2 m (32–63%) taller than the worst provenances, and between 0.5–1 m (15–40%) taller than the site mean height. The same GB seed lots have also shown good early growth in a similar series of trials planted in Ireland (Lally and Thompson, 2000) and at 13 sites in France, Germany, the Netherlands and Denmark (Madsen *et al.*, in Prep.).

The two Scottish *source-identified* provenances have generally grown slowly in England and Wales. However, on a very testing frost-prone Scottish trial site, the one Scottish provenance included had the best survival rate by year 12.

The majority of the European provenances come from registered *selected* seed stands and have generally shown average performance in the trials. Oak of central and western French provenances had poor survival at a testing site in Scotland (Cundall, 1999). Material from Hungary and Turkey has generally poor early vigour. The one provenance from the south of the Netherlands, (NL3), has proved to be vigorous and of good form in GB trials. However timber cores from selected plus-trees from registered Dutch oak stands had significantly larger early wood vessel size than British and Irish oaks, which could lead to a higher risk of 'shake' on drought prone sites (Hubert and Savill, 1999).

Recommendations for oak

Where good growth rates and/or rapid establishment are desired then the following recommendations should be followed:

- First choice of provenance should be a British *selected* seed stand, preferably growing in the same region of provenance as the planting site. This source will have been selected for its good phenotypic quality.

- If no GB *selected* stock were available then second choice would be seed from a *selected* seed stand in near continental Europe, preferably from Netherlands, northwest France or north Germany. The probability of late frosts should be considered when proposing movement of distant material. More local provenances are less risky where frost risk is substantial.

- Third choice is British seed from the *source-identified* category. The requirements of this category do not include phenotypic quality nor precise information regarding location. However, material of good phenotypic quality may be available in this category and growers should seek precise information about the source of the seed from the supplier. Good phenotypic quality is a more important criterion than geographical proximity alone.

- Seed from central and eastern European sources is **not recommended** and it would be better to delay planting rather than use such material.

Ash (*Fraxinus excelsior*)

Early results are available from ash provenance trials testing British and continental material at six sites in England and Wales (Cundall *et al.*, 2003; Cundall, 2002). Amongst the GB seed sources, the *selected* stand at Brockhampton (FRM identification fexST40-01SE) in Gloucestershire is particularly promising for vigour, lack of forking, good branching and stem straightness. By contrast, the northern seed source of Dunnottar (FRM identification fexST20-01SE) from Aberdeenshire (also a *selected* stand) has grown very slowly at an experimental site in Hampshire. A *source-identified* stand from North Yorkshire demonstrated good form and branching in the trials and is vigorous at two of the three sites where it was planted. Material from eastern continental Europe (e.g. from the Czech Republic, Germany) grows relatively slowly and may also have remarkably poor form (e.g. from Romania). By contrast several provenances from northern and central France showed good early vigour and acceptable form.

There are currently three registered *selected* stands of ash in GB and the approval of more stands of superior quality is highly desirable. In addition to the *selected* stands, the British and Irish Hardwood Improvement Programme (BIHIP) has established breeding seedling orchards (BSOs)

which integrate testing and production of improved seed (BIHIP, 2005; Barnes, 1995). The earliest of these is now beginning to produce seed and will be entered into the National Register of seed stands in 2006.

Recommendations for ash

- Ideally source the seed from a BSO or a *selected* seed stand. Otherwise seed should be collected from British *source-identified* stands exhibiting good phenotypes from similar or slightly more southerly latitudes than the planting site. As ash often seeds prolifically it should normally be possible to obtain British seed.

- Seed from northern France would also be acceptable in the southern half of Britain.

- Ash planting stock from eastern continental Europe is poor and should not be planted in GB.

Birch (*Betula pendula* and *B. pubescens*)

Early results from provenance trials, evaluating up to 40 Scottish and northern English sources planted at four contrasting Scottish sites, show that seed-sources from the south and east of that area are generally more vigorous than those from the north and west (Worrell *et al.,* 2000). The sources from the south and east flush earlier in the spring and lose their leaves later in the autumn than those from the north and west. Transfer of northern English silver birch (*B. pendula*) to Scottish sites gives an increase in growth rate compared with most local material, at least in the early years, but the long-term reaction of such provenances to spring and autumn frosts and exceptionally low winter temperatures – especially at more exposed sites – is not known. Care should be taken to avoid moving birch provenances over long distances, i.e. more than about 2° latitude (approximately 200 km). Similarly, birch shows strong adaptation to exposure and elevation and growers should be sensitive to the 300 m altitude banding of provenances described by Herbert *et al.* (1999) when planting. It is unlikely that there will ever be a shortage of seed of this prolific seed-producer, so it should not be necessary to import seed from continental Europe. There is strong experimental and silvicultural evidence for very poor survival and growth of Finnish birch in Scotland (Worrell *et al.,* 2000).

Recommendations for birch

- Ensure that the species of birch selected is appropriate for the site. Growers can be guided by Ecological Site Classification (Pyatt *et al.,* 2001; Ray, 2001).

- In Scotland use stock from one of the five registered *selected* seed-stands. Elsewhere, use seed from British stands of good phenotypic appearance, taken from similar or slightly more southerly latitudes than the planting site and from similar altitudes.

- Material from Finland, or any area with a more continental climate than Britain, should not be planted.

Sycamore (*Acer pseudoplatanus*)

Because sycamore pollen cannot be distinguished from that of field maple (*Acer campestre*) the origin of this species in the British Isles is obscure. Although usually regarded as a 'non-native', there is no compelling evidence that this is the case and it is certainly well naturalised. There is no information yet concerning from which continental origin, or origins, the GB populations are derived. Early results from up to ten provenances at five sites, four planted in England and one in Wales (Cundall *et al.,* 1998) indicate that most British provenances grow well at most sites. For example, the Chatsworth provenance gives a higher than average percentage of young trees of good form in provenance trials. Of four continental provenances tested, one from Denmark and one from Germany performed better than the British provenances on the sites where they were planted. Results of trials in continental Europe showed great variation but with no discernible geographic pattern (Tillisch, 2001). For example, a trial in Holstein, Germany, found that two local provenances growing only 50 km apart were dramatically different. This geographically patchy performance may be due to the fact that sycamore is insect-pollinated which will reduce gene flow through pollen transfer relative to wind-pollinated species. Under conditions of lower gene flow there would be greater local adaptation compared with wind-pollinated species such as birch, ash or oak.

Recommendations for sycamore

- Seed should be collected from GB stands of good appearance from similar or slightly more southerly latitudes than the planting site, and from similar altitudes.

- Seed from registered *selected* stands in western Europe should also be generally suitable.

Cherry (*Prunus avium*)

There is very little data on provenance choice for cherry in Britain, but there is anecdotal evidence that planting imported provenances can lead to wholesale failure. This suggests that careful provenance choice is very important. Commercial seed material available for this species may be poor because much of it is imported from continental Europe where some derives from cherry varieties grown for fruit. This can lead to trees with poor form, heavy branches and a high susceptibility to canker. Occasionally Morello varieties (*P. cerasus*) are imported by mistake. A programme of plus tree selection of native cherry has been undertaken by HRI International (now East Malling Research). These plus trees have been tested for canker resistance and growth rate and the best have been propagated through micro-propagation. Ten clones have been released as the Wildstar™ collection (Russell, 2002). These clones are available from a small number of commercial producers (for more information contact East Malling Research, email: enquiries@emr.ac.uk). A recent test of five of the Wildstar™ clones found that performance was variable between clones in terms of canker resistance and growth and suggested that the more expensive Wildstar™ stock should be planted in a mixture with unimproved material (Kerr and Rose, 2004). This would reduce costs and provide the opportunity for good plants of non-clonal origin to increase the genetic diversity of the stand. Untested clonal seed orchards of wild cherry, based on East Malling's plus tree selections, have been established for regions 30 and 40 (England and Wales, see Figure 2). These are now entered in the National Register as *Qualified* seed orchards and will come into commercial production in the next five to ten years.

Recommendations for cherry

- First choice should be for stock derived from the *qualified* seed orchards or consider the possibility of investment in clonal forestry with the Wildstar™ collection.
- Since there are no registered *selected* seed stands of cherry, second choice should be seed from *source-identified* stands in GB which should have the advantages of being the correct species and of being relatively well adapted.
- Avoid seed material of eastern European and Italian origin.

Beech (*Fagus sylvatica*)

Two provenance trials including a wide range of continental European material were established in 1996 and 1999. Early results are more likely to reflect adaptation to the nursery in Germany where the trees were raised and so current recommendations closely follow those of Lines (1987).

Recommendations for beech

- Either use planting stock from the Forêt de Soignes, Belgium, or from a *selected* seed stand in GB, preferably of the same region of provenance as the site.
- If no GB seed is available, use seed from registered seed stands in western Europe, e.g. Belgium, France, Netherlands or western Germany.

Walnut (common walnut, *Juglans regia* and black walnut, *Juglans nigra*)

Both species produce very valuable timber, but are susceptible to unseasonable frosts in autumn and spring. Hybrids of the two species are now also available and these exhibit very good form and vigour combined with late flushing. Nurse crops are also potentially important for the successful cultivation of walnuts for timber. Provenance/progeny trials of *J. regia* were established by Northmoor Trust at Little Wittenham, Oxfordshire, in 1998 (Hemery, 2001). Results after five years demonstrated the importance of late flushing as annual height growth is reduced by frost damage. In the trials two French provenances, of Tadjikistan and Iranian origin, and a Slovenian provenance performed consistently well over the three sites (Hemery *et al.*, 2005).

Recommendations for walnut

- Use planting material that is known to perform well in an environment as similar as possible to the planting site.
- In general seek late flushing provenances, for example the French variety of *J. regia* 'Lozeronne'.
- Hybrids between *J. nigra* x *J.regia*, developed in France, should also be considered.

Aspen (*Populus tremula*)

Aspen has not been an important timber species in the UK, but it is of great ecological value – especially as it is associated with a habitat for a number of rare insects which feed on dead aspen wood. Aspen is dioecious, so individual trees are either male or female, and when vegetatively reproduced the clones are similarly male or female. Although commercial propagation is largely vegetative and based on using root-suckers, it can also be propagated by seed (Worrell, 1995). Survival and height at six years after planting for several clones across five sites was reported by Mason *et al.* (2002), who found that good survival and growth could be obtained from local clones as well as from selected Swedish material.

Recommendations for aspen

- When established for conservation purposes, some care should be taken to use suckers or seed from a range of locally native clones rather than a few to avoid loss of genetic diversity.

- Plant both male and female clones. Mason *et al.* (2002) recommended that a minimum of 10 clones should be established in woods of 0.5–1.0 ha, 15 clones in those of 1.0–5.0 ha and >20 clones in woods of >5.0 ha.

Norway maple (*Acer platanoides*)

Results from trials at two sites (Kerr and Niles, 1998) show that good growth and form of Norway maple can be achieved from a wide range of sources in Europe but that material from further east, including Russia, had poor performance.

Recommendations for Norway maple

- Use seed from *source-identified* stands of good form in GB or, if such seed is not available, from *selected* stands in northwestern Europe.

- Avoid planting stock from eastern Europe and Russia.

Red oak (*Quercus rubra*)

Red oak is a minor species in GB but far more commonly grown in western continental Europe, particularly in France on dry, acidic sites (Savill, 1991). The timber can be used for furniture, flooring and internal joinery but needs to be treated for external use.

A trial of red oak was established in 1992 as a series of five provenance experiments planted in England: at the Forest of Dean, Arden near Coventry, West Downs in Surrey, the southern edge of the North York Moors and a small trial near Taunton in Devon. The trials contained up to thirteen provenances grown from seed imported from the USA and Canada. The provenances range from the State of Indiana in the southwest of the USA, up to the Province of Quebec in the northeast of Canada.

The experiments were assessed for height and form at 13 years after planting. The results indicate that provenances from Southern Ontario, the region between Detroit and Toronto (approximate latitude 42° 30' N; longitude 79°–82° W), consistently performed well in all the four main sites. In particular, collections from Chatham District, Aylmer/Simcoe Districts and Ridgeway, all in Ontario, Canada, were consistently above average for height growth and form after 13 years. Generally the poorest provenances were from further north; all the provenances north of 44° N were below average for height growth. The only exception to this consistent trend has been at the site near Taunton where the best provenance for height and form is Plaines de Kazabazua, Quebec (45° 56' N; 76° 06' W), otherwise a consistently poor performer elsewhere. One possible explanation for this result is that the trial was hit by late frosts on a number of occasions soon after establishment and this more northerly provenance was able to recover more rapidly than the southern provenances in the trial.

Recommendations for red oak

- Source seed from southern Ontario, in particular Chatham District (Ontario seed zone 38), Aylmer/Simcoe Districts and Ridgeway (both Ontario seed zone 37).

- Material from further north, e.g. Quebec or northern Michigan, should be considered on more frost prone sites.

Southern beech (*Nothofagus obliqua* and *N. procera*)

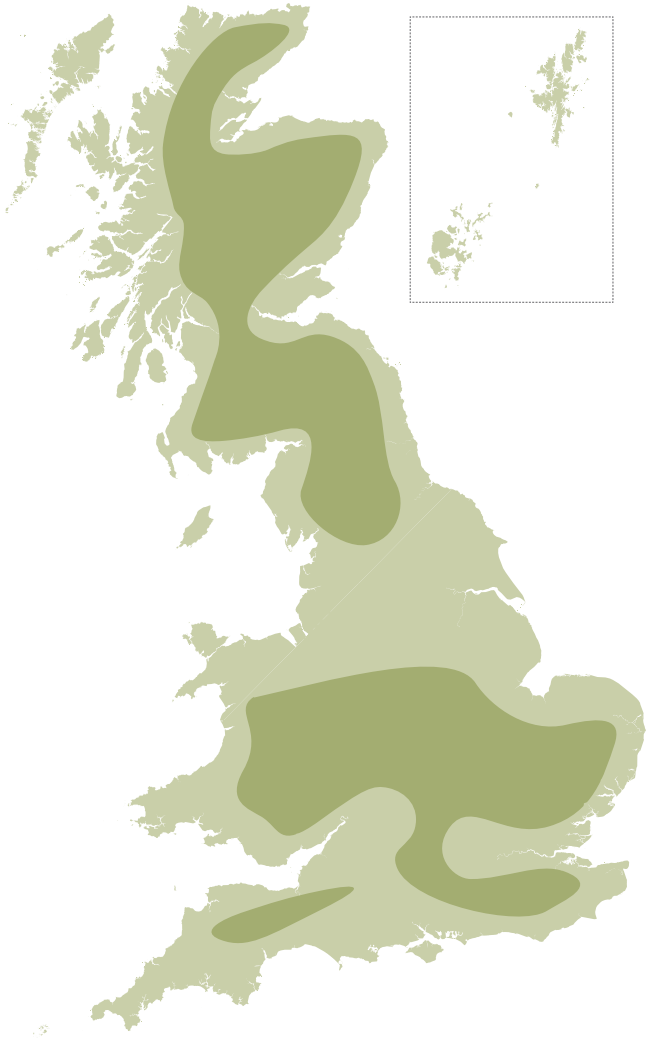
Southern beech grows rapidly with a normal rotation of 40–50 years. It usually shows excellent stem form. An extensive series of provenance trials of both *Nothofagus procera* (rauli) and *Nothofagus obliqua* (roble) obtained from their natural ranges in Chile was established across GB in 1979. Growth rate and frost susceptibility were

correlated with latitude of origin. GB provenances, raised from home collections taken from hardy individuals, produced better results than the directly imported material.

Both species flush in early spring and have no inherent protection against spring frosts. They may be killed by severe frost events, such as in 1980/1981, which are likely to occur once every 50 years in most areas of GB. In this regard they are similar to *Eucalypts*. The areas of GB where annual minimum air temperatures of –16°C or less are likely to occur once every 50 years are shown in Figure 3 (after Cannell *et al.,* 1989). Current models of climate change do not predict whether extreme frosts will become less frequent.

The climate most likely to be suitable for good growth of southern beech is within 20 km of the coast where highly productive stands can be grown.

Figure 3 Areas of Great Britain where an annual minimum air temperature of –16 °C or below are likely to occur once every fifty years (from Cannell *et al.,* 1989).



Recommendations for southern beech

- *N. procera:* the most suitable Chilean origins for British conditions are those from central Cautin (seed identification number 8332) and southern Malleco (seed identification 8331) provinces. Origins from Nuble (seed identification 8327) should be avoided or used only in locations with the mildest climate. Seed collections from successful British stands have produced good results and it also appears that the protected Argentinean forests may yield suitable material (Potter, 1987).

- *N. obliqua*: provided that the seed does not originate from further north than Malleco (8331) province, Chile, there appears to be little difference over most of GB between the performance of a range of *N. obliqua* origins. However, on climatically severe sites, the Llanquihue, Chile, (seed identification 8335) seedlot showed some advantage and this would probably be true of other Central Valley provenances. Home collections and Argentinean sources (seed identifications beginning with 82) again appear promising (Potter, 1987).

Eucalypts (*Eucalyptus* spp.)

There is increasing interest in planting eucalypt species in GB, predominantly for the woodfuel market. A series of trials of different eucalypt species was established between 1981 and 1985 to test their suitability to British conditions (Evans, 1980; 1986; Brooker and Evans, 1983). The establishment of the trials coincided with a period of particularly cold winters and hence unsuitable provenances were quickly identified. *E. gunnii* collected from high elevations (1100 m) in the Central Plateau region of Tasmania showed high levels of hardiness (Evans, 1986). An *E. gunnii* bred by AFOCEL in France for frost tolerance showed poor survival rates (8–9%) and should be avoided on risky sites (Evans, 1986). Interestingly, there is large within-provenance variation and Evans (1986) reported individuals of *E. gunnii, E. debeuzevillei* and *E. niphophila* that showed no signs of frost damage despite temperatures of –23 °C. Vegetative propagation from these individuals should be relatively straightforward and this approach would produce material able to grow across much of Britain.

On a milder site in Exeter that escaped the worst frosts, *E. delegatensis, E. nitens, E. johnstonii/subcrenulata* and *E. nitida* have all shown very high growth rates (e.g. top heights after five years of between 7–12 m), in particular

E. nitens (Evans 1986). These more productive eucalypts could be considered where there is a reduced risk of serious frost (Figure 3). A more recent assessment of one of the original 1981 trials in Thetford (East Anglia) confirmed the good performance and survival of *E. gunnii* after 21 growing seasons, but reported the total loss of *E. nitens* (Bennett and Leslie, 2003).

Recommendations for eucalypts

- *E. gunnii* from high elevation sites in central Tasmania represent the lowest risk origin for GB growers. However, direct imports of this provenance are likely to be variable in their tolerance to frost. If it were available, vegetatively propagated material from surviving trees in the 1980's trials would represent the most reliable stock.

- In milder locations, e.g. near the coast, or where rotations are planned to be short and the grower is aware of the risk, *E. nitens* is probably the most productive eucalypt suitable for GB conditions. High elevation origins (>1200 m) from Victoria, Australia should be preferred. *E. delegatensis* also performs well with the mainland Australian origins (high elevations >1200 m in New South Wales and Victoria) showing greatest frost hardiness (Evans, 1986).

GENERAL RECOMMENDATIONS

This Information Note covers those broadleaved species for which some trial data are available. Based on results from those trials, some very broad generalisations can be made which should be true of most species.

- Seed stock from eastern continental Europe is usually poorly adapted to GB in terms of growth rate and reduced survival. It may also be poorly adapted in terms of phenology and resistance to foliar disease. It should not be planted in GB.

- Southward movement of genetic material within GB (of the order of hundreds of kilometres) is likely to lead to a loss of vigour compared with local material.

- Northward movement of genetic material within GB (of the order of hundreds of kilometres) may result in a gain in vigour compared to local sources, but the long-term implications are not known. Such material may prove to be more susceptible to late spring frosts or early autumn frosts which may not be fatal but may lead to poor stem form due to forking. Low temperatures in exceptionally cold winters that may be experienced once or twice in a rotation may be more seriously damaging.

Using seed from a *selected* seed stand registered in GB has generally given rise to trees of better vigour and stem form when compared with that from a *source-identified* stand. Greater efforts should be made by growers and growers' associations to increase the number of registered stands in Britain. Details of the process and the criteria used to judge registration for inclusion onto the National Register can be obtained from: www.forestry.gov.uk/frm under the National Register section. An application form with guidance is also available.

ACKNOWLEDGEMENTS

The authors would like to thank the Technical Support Units of Forest Research who have maintained and measured the trials over many years. The authors would also like to thank Steve Lee and Bob Selmes for their comments and suggestions.

REFERENCES

BARNES, R.D. (1995).
The breeding seedling orchard in the multiple population breeding strategy. *Silvae Genetica* **44**(2–3), 81–88.

BENNETT, C.J. and LESLIE, A.D. (2003).
Assessment of a *Eucalyptus* trial at Thetford and implications for *Eucalyptus* as a biomass crop in lowland Britain. *Quarterly Journal of Forestry* **97**(4), 257–264.

BROADMEADOW, M.S.J. (2002).
Climate change: impacts on UK forests.
Forestry Commission Bulletin 125.
Forestry Commission, Edinburgh.

BROADMEADOW, M.S.J. and RAY, D. (2005).
Climate change and British woodland.
Forestry Commission Information Note 69.
Forestry Commission, Edinburgh.

BROOKER, M.I.H. and EVANS, J. (1983).
A key to Eucalyptus in Britain and Ireland with notes on growing eucalypts in Britain.
Forestry Commission Booklet 50.
HMSO London.

CANNELL, M.G.R., GRACE, J., and BOOTH, A. (1989). Possible impacts of climatic warming on trees and forests in the United Kingdom: a review. *Forestry* **62**(4), 337–364.

CUNDALL, E.P. (1999).
Evaluation and selection of seed-sources in British broadleaves. Report on Forest Research 1998–1999. TSO, Edinburgh. p27–33.

CUNDALL, E.P. (2002).
Ash: choosing a seed-source. *Forestry and British Timber* **October 2002**, 18–22.

CUNDALL, E.P., PLOWMAN, M.R., and CAHALAN, C.M. (1998).
Early results of sycamore (*Acer pseudoplatanus* L) provenance trials at farm forestry sites in England and Wales. *Forestry* **71**(3), 237–245.

CUNDALL, E.P., CAHALAN, C.M. and CONNOLLY, T. (2003).
Early results of ash (*Fraxinus excelsior* L) provenance trials at farm forestry sites in England and Wales. *Forestry* **76**(4), 385–399.

EVANS, J. (1986).
A re-assessment of cold hardy eucalypts in Great Britain. *Forestry* **59**(2), 223–242.

EVANS, J. (1984).
Silviculture of broadleaved woodland.
Forestry Commission Bulletin 62.
Forestry Commission, Edinburgh.

EVANS, J. (1980).
Prospects for the eucalypts as forest trees in Great Britain. *Forestry* **53**(2), 129–143.

FORESTRY COMMISSION (2004a).
Forestry statistics 2004.
Forestry Commission, Edinburgh.

FORESTRY COMMISSION (2004b).
The UK forestry standard – the government's approach to sustainable forestry, 2nd Edition.
Forestry Commission, Edinburgh.

HELSINKI DECLARATION (1993).
The Second Ministerial Conference on the Protection of Forests in Europe held in Helsinki. The declaration and resolutions can be obtained at www.mcpfe.org/resolutions/helsinki.

HEMERY, G.E. (2001).
Growing walnuts for fruit and timber in the UK: Conference at HRI East Malling. *Quarterly Journal of Forestry* **95**(1), 29–30.

HEMERY, G. E., SAVILL, P.S. and THAKUR, A. (2005).
Height growth and flushing in common walnut (*Juglans regia* L.): 5 year results from provenance trials in Great Britain. *Forestry* **78**(2), 121–133.

HERBERT, R., SAMUEL, S. and PATTERSON, G. (1999).
Using local stock for planting native trees and shrubs.
Forestry Commission Practice Note 8.
Forestry Commission Edinburgh.

HUBERT, J.D. (2005).
Selecting the right provenance of oak for planting in Britain.
Forestry Commission Information Note 76.
Forestry Commission, Edinburgh.

HUBERT, J.D. and SAVILL, P.S. (1999).
Improving oak: the first steps towards a breeding programme. *Quarterly Journal of Forestry* **93**(2), 117–125.

KERR, G., and NILES, J. (1998).
Growth and provenance of Norway maple (*Acer platanoides*) in lowland Britain. *Forestry* **71**(3), 219–224.

KERR, G. and ROSE, D. (2004).
An evaluation of five Wildstar™ clones of *Prunus avium* L. *Quarterly Journal of Forestry* **98**(4), 263–271.

LALLY, M. and THOMPSON, D. (2000).
Which oak sources are best for Irish conditions? Making headway with forest research.
Coillte Research and Development Information Note 20.
Coillte Research Lab, Co Wicklow, Ireland.

LINES, R. (1987).
Choice of seed origins for the main forest species in Britain. Forestry Commission Bulletin 66. HMSO, London.

MADSEN, S.F., KONIG, A.O., KLEINSCHMIT, J., CUNDALL, E.P., DUCOUSSO, A. and DEANS, J.D. (In preparation).
International 1989 – Series of *Quercus petraea* (Matt,) Liebl. Provenance Field Experiments: Establishment and early Variation of Growth and Survival.

MASON, B., EASTON, E., and ENNOS, R. (2002).
Variation in aspen in Scotland: genetics and silviculture. In: *The Biodiversity and Management of Aspen*

Woodlands: Eds. Cosgrove, P. and Amphlett A., Proceedings of a one-day conference held in Kingussie, Scotland, on 25 May 2001, 45–55. Published by The Cairngorms Local Biodiversity Action Plan, Grantown-on-Spey, Morayshire, Scotland.

POTTER, M.J (1987).
Provenance selection in *Nothofagus procera* and *Nothofagus obliqua*. Research Information Note 114/87/SILS. Forestry Commission, Farnham.

PRYOR, L.D. (1976).
Biology of eucalypts. Studies in Biology No.61. Edward Arnold.

PYATT, D.G., RAY, D. and FLETCHER, J. (2001).
An ecological site classification for forestry in Great Britain. Forestry Commission Bulletin 124.
Forestry Commission, Edinburgh.

RAY, D. (2001).
Ecological site classification. A PC-based decision support system for forestry in GB.
Forestry Commission, Edinburgh.

RUSSELL, K. (2002).
Wild cherry programme gets star rating. *Forestry and Timber News*, Issue 1, March 2002, Woodland Owners Supplement, p4–6.

SAMUEL, C.J.A. (2003).
Recent changes to the control of forest reproductive material. Forestry Commission Information Note 53, Forestry Commission, Edinburgh.

SAVILL, P.S. (1991).
The silviculture of trees used in British forestry.
C.A.B. International, Wallingford, Oxon, UK.

SHEPPARD, L.J. and CANNELL, M.G.R. (1987).
Frost hardiness of subalpine Eucalypts in Britain. *Forestry*, **60**(2), 239–248.

STATUTORY INSTRUMENTS (2002).
No.3026. The Forest Reproductive Material (Great Britain) Regulations 2002.

TILLISCH, E. (2001).
AEren traenger sig frem. (The spread of sycamore) *DST – Dansk Skovbrugs – Tidsskrift*, **86**(1), p96.

WORRELL, R. (1992).
A comparison between European continental and British provenances of some British native trees: growth, survival and stem form. *Forestry* **65**(3), 253–280.

WORRELL, R. (1995).
European aspen (*Populus tremula* L.): a review with particular reference to Scotland, 1. Distribution, ecology and genetic variation. *Forestry* **68**(2), 93–105.

WORRELL R., CUNDALL, E.P., MALCOLM, D.C. AND ENNOS, R.A. (2000).
Variation among seed sources of silver birch in Scotland. *Forestry* **73**(5), 419–435.

Enquiries relating to this publication should be addressed to:

Dr Jason Hubert
Forest Research
Northern Research Station
Bush Estate
Roslin
Midlothian EH25 9SY

T: 0131 445 6947
F: 0131 445 5124
E: jason.hubert@forestry.gsi.gov.uk

www.forestresearch.gov.uk

ISSN 1460-3802
ISBN 0-85538-696 7

© CROWN COPYRIGHT

FCIN082/FC-GB(CLA)/ALDR-1.5K/MAY06