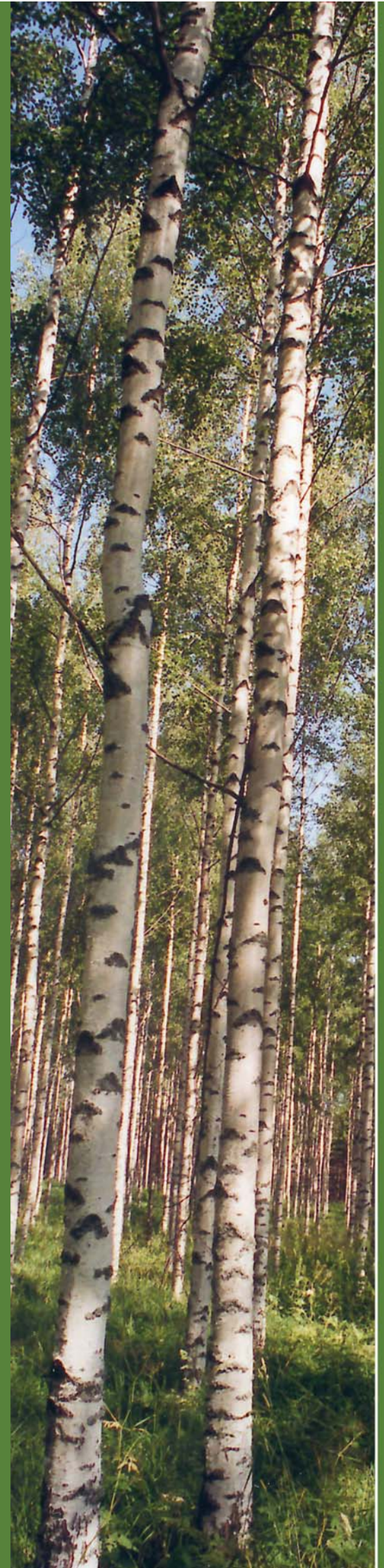

The Improvement of Irish Birch

Phase 1: Selection of individuals and populations

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COFORD
NATIONAL COUNCIL FOR FOREST RESEARCH & DEVELOPMENT

The Improvement of Irish Birch

Phase 1: Selection of individuals and populations

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Foreword

When we were developing our current R&D programme many stakeholders highlighted the need for more work on broadleaves, especially native species. While work was going on in ash and oak, very little was being done with birch, one of the few native species that has a timber potential.

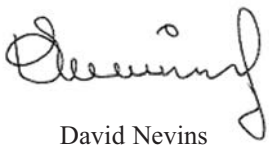
The planting of birch has increased in recent years, mainly for biodiversity reasons where it is used in mixtures with conifers to increase species diversity. However, the planting stock that is used is typically from wild, unimproved sources. Generally speaking, the form is poor, with little prospect of commercial timber being produced. Yet birch is a valuable tree species in Finland and other Nordic countries, where it is used in many high value end uses, such as flooring and furniture, and as a feedstock for high quality paper products. Growth in these uses is relatively recent; 30 years ago birch was regarded as a weed species and was removed, often at great cost, from young stands where it was competing with species such as Scots pine. Today there is an active breeding programme with the objective of producing higher quality stems and better wood quality. Because birch has a relatively short lifespan, and flowers early in life, improved seed can be obtained and deployed earlier than in many other species.

With these considerations in mind COFORD awarded a contract to Teagasc and University College Dublin to begin the first phase of improvement: to select families of individual birch trees of vigorous growth and good form throughout the island. In all seed from 121 families was collected, germinated, grown on, and planted in three replicated field trials. The report outlines the criteria used for selection and why these were used. A very useful spin-off is that for the first time we have a good knowledge of the distribution of both species of birch in the country.

The report essentially brings the work up to the end of 2001. Since then there are early indications emerging from the field trial of differences in growth and form between the different families. This variation is a more reliable indicator of performance than what is found at the collection site, where form and growth are very much influenced by soil and other conditions. A series of measurements have been conducted over the past years at the sites – the analysis of these data will be reported on in a future COFORD publication.

The advent of the Native Woodland Scheme and the growing use of birch in landscaping have presented new opportunities for the improved seed that will flow from this project. We eagerly await progress and look forward to birch playing a more significant role in the future in Irish forestry.

Dr Eugene Hendrick
Director



David Nevins
Chairman

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Contents

Summary

Birch is a native Irish broadleaved tree. Two species occur naturally in Ireland, i.e. 'downy' birch (*Betula pubescens* Ehrh.) and 'silver' birch (*Betula pendula*[2] Roth). *Betula* is an important commercial genus in several countries. It produces a white timber which has a strength and density similar to beech which can be used for high quality pulp, sawlog and veneer. Relatively little birch is grown commercially in Ireland, although there are markets for birch products that are presently satisfied by imports. This project examines the possibility of introducing birch as a commercial tree for Irish forestry. Currently there is no source of improved planting stock for Ireland. This study identified sources of native birch of superior quality phenotype and initiated the establishment of an Irish birch quality improvement programme using a number of methods.

Phenotypically superior Irish *Betula* stands and individuals in both Southern and Northern Ireland were identified and seed was collected from these sites. Seed from poorer quality trees was also collected in certain circumstances in order to include populations from a wide geographic range or in cases where populations are under threat of destruction. (Additional seed was obtained from German, Polish, Dutch, French and Scottish sources.) This collection was the main source of planting material for field tests that were established in Spring 2001.

- A gene bank was established by grafting scionwood from superior phenotypes. Establishment and performance of 43 grafted clones was recorded. Grafted plants achieved heights of 199 ± 28 cm after two growing seasons. Growth and form differences were apparent between clones at this stage.
- The gene bank doubles as an indoor clonal seed orchard. Techniques for producing viable seed from controlled crosses between grafted plants of superior phenotype were developed with viable seed harvests being made from grafts as young as six months of age. Seed was produced from 46 *B. pubescens*, three *B. pendula* and six inter-specific controlled crosses in 1999. Polymix pollinations were carried out with both species in 2000 and the resulting seed was sown in Spring 2001 for field testing.
- Clonal trees were produced from one clone of *B. pendula* using *in vitro* micropropagation. Shoot multiplication rates of x3 per 25d and *in vitro* rooting rates of 100% after 14 days were achieved. Plantlets were successfully weaned into a peat-based medium. Three *B. pubescens* clones were successfully initiated into *in vitro* culture, two of which were derived from controlled crosses between plants of superior phenotype. A series of half-sibling clones from two superior phenotype trees has also been established in culture and ten clones have been weaned. Clonal material will be used in the field trials to estimate environmental influences on birch and to identify traits with a strong genetic link.
- A database containing tree, site and soil information was compiled. General information on the occurrence of birch in Ireland has also been gathered, and can be used to build a first approximation birch distribution map.

This document explains why birch has been selected for forestry research and reports progress to the end of 2001. It also places the Irish birch improvement programme in context relative to research in other countries. This report, therefore, describes not just this project but gives an overall picture of birch past, present and future in Ireland.

2 Older references to *B. pendula* may appear as *Betula verrucosa* Ehrh.

General Introduction

The *Pilot Study for the Improvement of Irish Birch* was originally a two-year COFORD-funded[3] research project designed to promote biodiversity in Irish forestry and to develop two species with commercial potential, namely *Betula pendula* Roth and *B. pubescens* Ehrh. Funding was extended for an additional year to ensure the establishment of field trials of selected material. The project was a collaboration between University College Dublin Botany Department (Prof. Martin Steer and Dr Niamh O'Dowd) and Teagasc, Kinsealy, Forestry Unit (Mr Mike Bulfin and Mr Toddy Radford). Teagasc was involved because of the potential for birch in farm forestry and because of the knowledge base and suitable research facilities for broadleaf research at Kinsealy Research and Development Centre.

In 1999 an inventory by Coillte estimated the forest estate of Ireland at 9% of land cover. The national forestry strategy projects a figure of 17% by 2035, of which 20%[4] will be broadleaved trees (Anon. 1996). The advised 10% minimum broadleaf requirement for all sites is not economically feasible on difficult sites as quality broadleaf tree production generally requires greater fertility and shelter than conifer species. It was proposed that birch has a role to play within the national forestry strategy as:

- it has the potential to satisfy the 10% minimum commercial broadleaf requirement on sites with poor quality soil;
- growing birch would lead to increased diversity of Irish forestry species;
- *B. pendula* and *B. pubescens* are native species;
- it produces high quality timber;
- it offers a shorter rotation than most other broadleaved trees (Barrett 2000). This is important as most current afforestation is being carried out by farmers and private individuals who want a 'quick' return (Appendix 1).
- It can be used as a nurse tree for other timber species.
- Other European *Betula* improvement programmes have shown this genus to be amenable to form and vigour improvement. In Finland, *B. pendula* is reported to have better productivity, form and timber quality than *B. pubescens* (Eriksson *et al*. 1997, Verkasalo 1997, Bhat and Karkkainen 1980). In Germany *B. pubescens* shows greater productivity than *B. pendula* (Kleinschmit 1998). Therefore, it was considered important to work with both species in order to assess their relative performance in different environments.
- Birch has a high landscaping and conservation value and is a suitable genus for riparian buffer zones (Worrell 1999).
- Gene conservation is becoming an issue as imported birch threatens to dilute the native gene pool (Fennessy *et al*. 2000). It was, therefore, considered important to identify native material.
- *B. pendula* occurs naturally on free-draining mineral soils while *B. pubescens* is more tolerant of poorly-drained soils and peats. Working with both species will broaden the range of sites on which birch can be grown.
- In a specifically Irish context, 55,000 hectares of Bord na Mona industrial cutaway peatland with forestry potential will become available in the next 30 years. Birch has been listed as a potential species for this re-afforestation programme (Jones and Farrell 1997a,b).

Birch appears to grow vigorously in Ireland but information on its performance is limited. A concurrent COFORD/Coillte-funded project aimed at evaluating the growth rate of Irish birch suggests that unmanaged stands of Irish *B. pubescens* have the potential to achieve up to yield class 8, when the British Forestry Commission yield model is applied (Barrett 2000). The fastest growing tree observed achieved a diameter [at 1.3 m] of 25 cm in 32 years. Studies of managed, even-aged stands are required to provide further information on the growth potential of Irish birch.

Despite its rapid growth, the form of Irish birch is generally too poor to yield commercial quality stems. The *Pilot Study for the Improvement of Irish Birch* is the foundation for a programme aimed at producing a source of quality planting stock for the Irish forestry industry. Figure 1 outlines the basic strategies

3 National Council for Forest Research and Development.
4 Negotiations are under way to increase this figure to 30%.

employed to achieve this aim. Superior phenotype identification and selection were the key elements. Production of material from these sources for field testing was the objective of the project.

Three types of material from phenotypically superior sources were produced for field testing:

- Provenance and single parent progeny trials of half-siblings were established using seed collected from phenotypically superior stands and individuals.
- Single parent progeny trials of full-siblings were established using seed from controlled crosses in an indoor seed orchard.
- Clonal material produced from superior phenotypes using micropropagation techniques was also planted.

In the long-term, the trials could be used to answer several key questions:

- What are the growth rates of *Betula* in plantation conditions on different sites?
- What are the heritabilities of birch growth and form characteristics?
- What are the environmental influences affecting *Betula* growth and form?
- Can factors be identified for early selection of desirable *Betula* characteristics?
- Which provenances and individuals are commercially superior?
- Which provenances and individuals perform best on each site type?
- What are the wood properties of Irish *Betula*?
- Does site type/provenance influence wood properties of Irish *Betula*?
- Can management guidelines for Irish *Betula* be established?

Following assessment after approximately 15 years, the best 10% of the trees will be selected and grafted to form a seed orchard. Seed from these trees will be used to establish new progeny trials and the cycle of tree improvement will thus continue (Figure 1). The remaining trees will be thinned and managed in a commercial manner with samples being taken for studies on growth rate and wood properties.

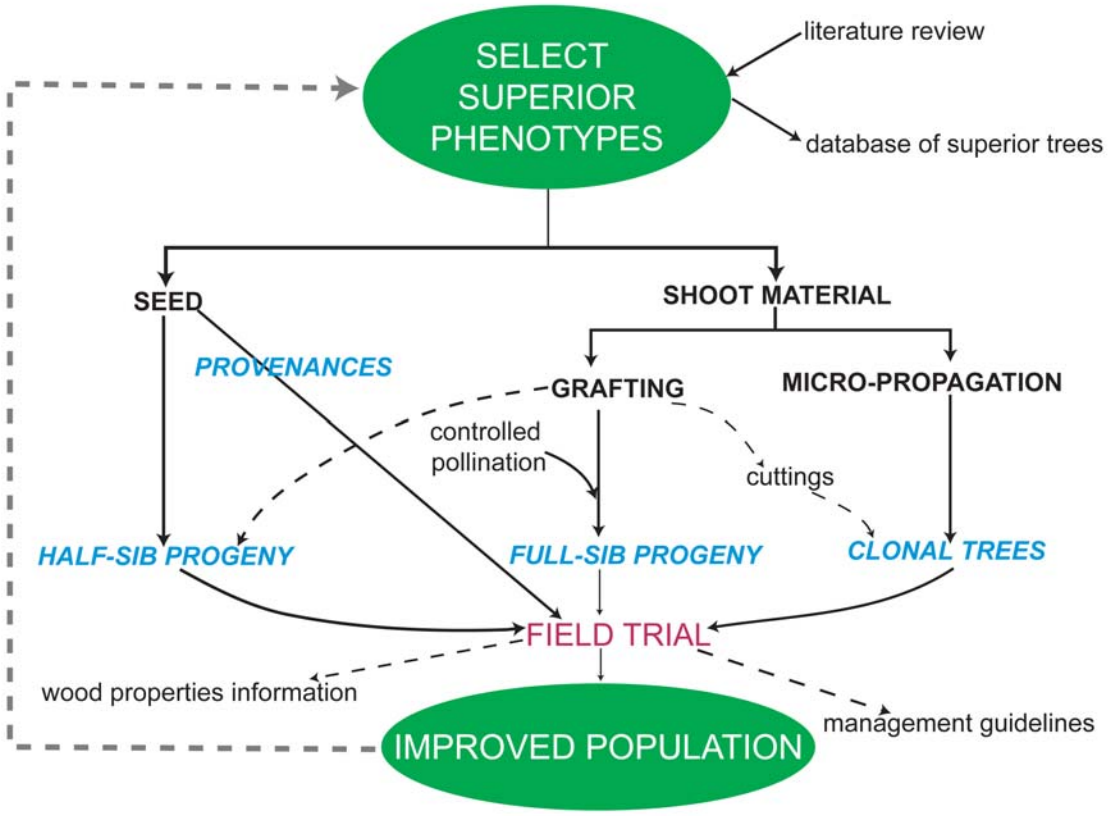


Figure 1: Summary diagram of the basic strategies employed in the improvement of Irish birch.

An Introduction to Birch

Taxonomy

The genus *Betula*, commonly known as birch, belongs to the family Betulaceae. The Betulaceae is comprised of six genera (*Betula* L., *Alnus* Miller, *Carpinus* L., *Corylus* L., *Ostrya* Scop. and *Ostryopsis* Decne.) distributed throughout the northern hemisphere, except for *Ostryopsis* which is endemic to eastern Asia. Phylogenetic analysis supports the division of the Betulaceae into two subfamilies, Betuloideae and Coryloideae (Chen *et al*. 1999). Betuloideae includes *Alnus* (alder) and *Betula* (birch) and the subfamily Coryloideae is composed of *Corylus* (hazel), *Ostryopsis*, *Carpinus* (hornbeam) and *Ostrya* (hop hornbeam).

There are approximately 50 species of *Betula* globally (Atkinson 1992), all of which occur in the northern temperate zone. There are two native species of birch in Ireland, *B. pendula* Roth (silver birch) and *B. pubescens* Ehrh. (downy birch). A third dwarf species, *B. nana* L. (dwarf birch), became extinct after the last ice-age as the climate warmed and *B. pendula* and *B. pubescens* spread across the Irish landscape. *B. nana* is still found in Scotland at the southern edge of its range and a new finding was reported in 2000 in the Kielder Forest District in eastern Cumbria.

The identification of *Betula* in Ireland and the United Kingdom (UK) is complicated by the fact that the morphological features of the genus are highly variable. The confusion about the taxonomic classification of *B. pendula* and *B. pubescens* is discussed by Gardiner (1984), who analysed the infra-specific variation found in *B. pubescens*. He suggests that this species can be divided into two subspecies in the Scottish Highlands, ssp. *tortuosa* and ssp. *pubescens*. He further suggests recognition of the variant *B. pubescens* ssp. *tortuosa* var. *microphylla* C.J. Hartman in this region. A series of *B. pendula* cultivars are recognised which exhibit a large range of morphological variation (Schilling 1984). One notable variety, *B. pendula* Roth var *carelica* Merckl. (curly or Karelian birch), is highly prized for its unusual timber texture which originates from the combination of wavy grain and dark-coloured brackets-, comma-, dot- or V-shaped inclusions which gives the timber a marbled appearance (Velling *et al*. 2000).

The question of hybrids further serves to complicate the identification of *Betula* species (see also the section on birch genetics). It is common for trees of intermediate morphology to be designated as hybrids. Counting chromosome numbers for such individuals has often resulted in the tree being identified as *B. pubescens* (Lindquist 1947). In order for hybridization to occur there must be an overlap in the flowering period of the species and there should be no absolute incompatability mechanism preventing fertilization or embryo development. Incompatability does occur between *B. pubescens* and *B. pubescens* but it is not complete (Brown and Williams, 1984, Haagman 1971). In Fennoscandia the birch assemblage consists of *B. pendula*, *B. pubescens* (ssp. *pubescens* and ssp. *czerepanovii*) and *B. nana*. In the northernmost region, the short growing season and reduced temperature sum induces synchronous flowering in these three species, thereby enabling hybridisation to occur and creating a broad range of phenotypes and genotypes in the sub-arctic region (Wagner *et al*. 2000). In fact, *B. pubescens* ssp. *czerepanovii* itself is believed to have originated through introgressive hybridisation between *B. pubescens* and *B. nana* (Karlsson *et al*. 2000). In Scotland, *B. pendula* flowers before *B. pubescens* but the presence of receptive female flowers of the latter during pollen-shed of *B. pendula* has been noted (Aston 1975). It is therefore possible that hybrids do occur in the wild in the UK. Worrell (1999) suggests that hybrids constitute no more than 1% of the UK birch population. There are currently no data available for Ireland but hybrids should be considered a possibility when dealing with *B. pubescens* and *B. pendula*.

Distribution

Atkinson (1992) describes the broad climatic tolerance of these two species. *B. pubescens* extends eastwards through Siberia to approximately 127ºE while *B. pendula* extends only to 103ºE. *B. pubescens* occurs in Iceland but *B. pendula* is absent. *B. pubescens* also occurs further north than *B. pendula*

while *B. pendula* extends further south than *B. pubescens* (Jalas and Suominen 1976). The northern limit for both appears to be determined by protection from cold north-easterly winds (Anderson *et al*. 1966) and the southern limit appears to be restricted by drought conditions (Peinado and Moreno 1989). In Ireland, birch distribution is largely influenced by human activity. Kelly and Iremonger (1997) found *B. pubescens* present in wetland woods in all regions of Ireland in addition to generally being the dominant tree species on acid peats, whether drained or waterlogged.

Birch is a pioneering tree and usually occurs in woodland gaps and clearances or after fire. It does not achieve the stature or long life of many of the other temperate hardwoods such as oak (*Quercus robur* L. and *Q. petraea* (Matt.) Liebl.), sycamore (*Acer pseudoplatanus* L.), ash (*Fraxinus excelsior* L.) and beech (*Fagus sylvatica* L.) (Joyce 1998). Irish birch rarely exceeds 24 m in height or a diameter greater than 35 cm. Trees mature after about 60 years and go into decline, seldom exceeding 100 years of age (Gimingham 1984). Silver birch grows best on well-drained, lighter mineral soils but also grows on heaths, shallow peat and gravels. Downy birch also grows well on fertile mineral soils but is tolerant of wet or waterlogged conditions and of heavy clays and deeper peats. The two species can occur together and hybrids between them may be possible.

Birch can rapidly colonise newly-cleared or scarified ground. This invasiveness in areas of human activity such as forestry, farming and cut-over peatlands is unwelcome. As a result, birch is generally regarded as a weed which must be removed. This problem is compounded by the fact that birch has very poor natural durability when used untreated outdoors, leading to the perception that birch timber has no value other than as fuel wood. The generally very poor form of Irish birch is yet another reason for it being neglected. Birch is generally limited to growing on poor sites and this, allied with removal and coppicing, maintains a paucity of mature, commercial quality birch in Ireland.

Morphology

As discussed previously, the identification of *Betula* at species level can be difficult and this is not helped by the taxonomic confusion of this genus. It is not uncommon for *B. pendula* and *B. pubescens* to be confused in Ireland and the UK (Worrell and Malcom 1998). Many methods have been developed for distinguishing the two species, each with varying levels of reliability. Morphological methods will generally distinguish *B. pendula* but *B. pubescens* exhibits a more plastic morphology and can sometimes be mistaken as *B. pendula*. Table 1 summarises the main morphological features of the two species. Irish *B. pendula* can generally be distinguished by its leaf shape but *B. pubescens* can also exhibit leaf characteristics which similar to *B. pendula*. One of the most reliable morphological characters in the author's experience is the 'downy' young shoot tip of *B. pubescens* versus the rough 'warty' shoot tip of *B. pendula* but this is by no means definitive. In our experience, *B. pendula* has never been mistaken as *B. pubescens* but *B. pubescens* has been mistaken for *B. pendula* on occasion (about 10%). In such cases we use the colorimetric test of Lundgren *et al*. (1995) to assist in our identifications.

This simple chemical test helps to distinguish the two species. It detects a phenolic diarylheptanoid glycoside called platyphylloside which occurs in the inner bark of *B. pendula* and its hybrids but not in the bark of *B. pubescens*. The test cannot distinguish between pure *B. pendula* and *B. pendula* hybrids but it does allow rapid screening for *B. pubescens* (Lundgren *et al.* 1995). It is cheap (chemical reagents cost 0.5 p/sample) and quick (2 minute sample preparation time; 3 to 4 hour reaction time). This test is particularly useful for identifying scionwood or trees in the winter when leaves are not available for morphological analysis. It should be added that other, more complex methods such as chromatography (Julkunen-Tiitto *et al*. 1996) and spectroscopy (Atkinson *et al*. 1997) have also been developed for identifying birch species.

Genetics

Chromosome counting is probably the most reliable method for distinguishing *B. pendula* and *B. pubescens*. Chromosome numbers in *B. pendula* and *B. pubescens* are 2n=28 and 2n=56 respectively, although these numbers are not constant (Brown and Williams 1984). Some studies suggest that the haploid number is n=7 not n=14 (Brown and Al-Dawoody 1979) although a more recent review by Eriksson and Jonsson (1986) refers to *B. pendula* as a diploid and to *B. pubescens* as a tetraploid.

Studies of hybridisation between *B. pendula* and

Table 1: Summary of identifying characteristics for *Betula pendula* Roth and *B. pubescens* Ehrh.

	B. pendula	***B. pubescens***
Chromosomes	2n = 28	2n = 56
Habit	30 m high smooth, silver-white upper bark black, 'diamond' fissures on lower bark	25 m high smooth, brown, grey or white upper bark may have fissures on lower bark, tend to have horizontal banding on bark
Branches	pendulous	upswept, pendulous or spreading
Twigs	no hairs with small, rough warts buds not sticky	brown/black, can be pubescent when young; may have smooth bumps buds may or may not be sticky
Leaves	no hairs generally triangular extended tip base angular double-serrated margin. Prominent primary teeth curve up to apex. petioles 10 to 18 mm in length lighter green than *B. pubescens*	pubescent, at least on lower veins shape very variable; generally oval short tip but may be extended base rounded to angular generally single toothed margin. Teeth don't curve up to apex. petioles 5 to 20 mm in length usually duller green leaf than *B. pendula*
Reproduction	monoecious	monoecious
Male flower	winter: 1 to 2 cm long x 4 mm wide ripe: 2 to 6 cm long x 6 mm wide 2 to 4 together at ends of small shoots	same
Female flower	erect, appear April-May pale-green when immatue 2 to 4 together at ends of small shoots	same
Seed	catkins ripen in August-September >100 seeds per catkin maximum germination rate 40%[5]	same
Environment	Almost exclusive to mineral soils	Common on peat soils

B. pubescens have shown that there are incompatibility barriers between the two species. Nonetheless, hybrids are possible. Crosses in which *B. pubescens* is the pollen donor and *B. pendula* is the seed tree have a higher success rate than the reciprocal cross (Johnsson 1951, Stern 1963, Hagman 1971). It appears that *B. pendula* pollen tubes cannot penetrate the style of *B. pubescens* (Hagman 1971). Hybrids are generally expected to have 2n=42 chromosomes and individuals with this complement have been reported (Helms and Jorgensen 1925; Johnsson 1951; Varaama 1969; Hagman 1971; Kenworthy *et al*. 1972; Brown and Al-Dawoody 1977). Varaama (1969) reviewed reports of twenty individuals with intermediate chromosome numbers. Of these, only two were deemed to be hybrids. Nine were unclassifiable from the available data but the remaining nine trees were classified as autotriploids of *B. pendula*. It should therefore be borne in mind that 42 chromosomes does not necessarily indicate a *B. pendula* x *B. pubescens* hybrid. Nor, as Brown and Al-Dawoody (1977) point out, do all hybrids always possess 42 chromosomes. Further complicating the issue is a study introducing possible evidence of apomixis (Hagman 1971).

As discussed, there is evidence of natural hybridisation between *B. pendula* and *B. pubescens* in UK populations of birch (Nokes 1979, Brown *et al.* 1982). Brown and Williams (1984) reported that hybrids grown from seed from a *B. pendula* tree tended to be sterile. One, when crossed as a pollen donor with *B. pendula*, produced seed which was only 1% germinable and produced no seed when used as a seed parent. Crosses involving other hybrid individuals failed to produce seed. Brown and Williams (1984) suggest that, if this is a typical scenario, it is likely that hybrids do not play an important role in natural UK populations.

[5] This project achieved germination rates of up to 75% with green *B. pendula* seed.

Inbred lines of *B. pendula* were produced by the Foundation for Forest Tree Breeding in Finland for use in F1 hybrid production. The aim was to self plus trees for several generations to obtain 'clean lines' with high levels of homozygosity. These lines were then to be crossed in the hope that superior F1 hybrids would be obtained. They found severe inbreeding depression in the inbred lines after three generations with decreasing height and diameter (Wang *et al*. 1996). Induced mutations were studied but no substantial genetic gain was obtained from artificial polyploids (Sarkilahti 1990, Sarkilahti and Valanne 1990).

In the context of Ireland, there is little information available on the genetics of *B. pendula* or *B. pubescens*. A study using AFLP techniques successfully identified the paternity of seedlings from a *B. pubescens* polymix cross of superior phenotypes. This is the only Irish birch genetic study to date. Genetic diversity in Irish birch has not been examined at either the phenotypic level or the genotypic level. One reason for carrying out the *Pilot Study for the Improvement of Irish Birch* was to identify, where possible, native stands of birch. This is an important exercise as there is an increasing threat of the native gene pool being diluted and replaced by foreign imports (Fennessy *et al.* 2000).

Seed production and germination

Birch bears male and female flowers on the same tree but in separate inflorescences called catkins. The male catkins are produced in mid-summer and overwinter on the dormant branches, eventually ripening to produce pollen in March-April. The erect, green female catkins emerge before the leaves in late spring from morphologically distinct buds known as 'short shoots'. These buds can be distinguished from vegetative buds.

Following pollination the female catkin becomes pendulous as the seed develops. Female catkins ripen between late August and early October in Ireland. Most seed falls within 50 m of the source tree (Sarvas 1948). Each catkin yields about 100 seeds although there are reports of up to 450 seeds per catkin (Perala and Alm 1990). Germination levels are generally low at approximately 40%. Under controlled conditions in Finnish seed orchards, it is possible to produce approximately 400 seeds per catkin (Dr Martti Lepisto, pers. comm.). Seed viability declines rapidly over time. For example, Granstrom and Fries (1985) found that *B. pendula* and *B. pubescens* seed on the forest floor retained 6% viability after one year, 3% after two years and only 1% after three years.

Seed germination is inhibited by the presence of a water-soluble substance in the seed coat (Black and Wareing 1959). This compound appears to increase the embryo's oxygen and light requirement. Stratification removes this substance and allows germination to proceed in the absence of light. Stratification also eliminates the inhibitory effect of low temperature on germination (Cabiaux and Devillez 1977).

It was noted during the course of this project that the wing size of seedlots varies considerably. Wings may aid in seed dispersal but they may also play a role in seed germination. It was observed that as the surface of the seed bed dries out, the wings 'clamp' the seed to the soil surface and trap moisture beneath the seed. The seed does not re-float under conditions simulating heavy rain. Seeds with large wingspans (4 to 5 mm) may have an advantage on bare soil over seeds with small wingspans as they can trap more moisture. This may be a useful adaptation to drought conditions. Further study would be interesting as this may have implications for broadcast sowing onto cutover peat.

Seedling growth

Seedling mortality rates can reach 90% in the first year, often due to desiccation (Miles and Kinnaird 1979). The seed is very light and often becomes stuck to unsuitable surfaces (perhaps a disadvantage for large-winged seeds) or the young seedling radicle cannot reach or penetrate through the litter to the soil surface. Bare or disturbed ground resulting from clearing or burning favours seedling survival although organic ash can be prone to drying. Competition from other vegetation, frost heave and browsing also takes its toll. In Finland, there is currently a breeding programme to produce birch which is unpalatable to hare and vole (Rousi *et al.* 1997).

Timber properties

Birch grows rapidly and produces a pale, fine-grained timber in which the heartwood and sapwood have similar appearance, and which is comparable to beech and oak in strength and density (Table 2). In fact, the strength-to–weight ratio of birch clear-wood exceeds that of any other native European hardwood

Table 2: Timber properties of birch compared with several other timber species.

	Density (kg/m^3)	Max. bending strength (N/mm^2)	Stiffness/elasticity (N/mm^2)	Compression (N/mm^2)
Birch	673	123	13,300	59.9
Beech	720	118	12,600	56.3
Oak	689	97	10,100	51.6
Scots pine	513	91	10,000	47.4
Sitka spruce	384	67	8,100	36.1
Sycamore	560	99	9,400	48.0

Source: Lavers (1983)

commercial species and that of most softwood species. The timber is suitable for high quality pulp, sawlog, veneer and turnery. Birch is also an excellent fuel wood with a calorific yield of 18.8 to 19.9 MJ/kg (Bossel 1980, Domalski 1987). The anticipated rotation period for Ireland (35 to 45 years) is comparable to that of Sitka spruce. Dunham *et al*. (1999) state that trees of 30 cm diameter are certainly possible to produce in the UK within 45 years, while Cameron refers to 40 year rotations on good UK sites (Anon. 2000). Yield classes of 6 to 10 are estimated on a 40 to 60 year rotation, also in the UK, by Worrell (1999).

There is market potential for birch in Ireland as it is suitable for making furniture, doors, flooring and panel face veneer. Birch plywood is used in aircraft, musical instruments, models, toys, skis and other sports equipment. The wood does not taint food products and is used for packaging items such as fruit, vegetables and cheeses. Currently, most birch products are imported. Import figures for Ireland are not available but it is estimated that the UK imports over 20,000 tonnes of birch annually, excluding birch products (Worrell 1999).

Birch also produces high quality pulp. The long thin-walled fibres and high hemi-cellulose content give it good strength properties, high density and low light scattering ability (Tammisola *et al*. 1995). Nepveu and Velling (1983) have shown that the basic density and shrinkage characteristics of birch wood are strongly inherited and can be selected in improvement programmes.

Niche markets for birch products

In addition to producing quality timber, birch can be used for other purposes. Production of birch sap wine and shitake mushrooms are two niche markets. In addition, a compound called betulin is found in the bark of white birches (including *B. pendula* and *B. pubescens*). This can be converted to the pentacyclic triterpenoid derivative, betulinic acid which has reputed anti-cancer properties. Initial results suggest that it selectively kills human melanoma cells *in vitro* while leaving healthy cells intact (Selzer *et al*. 2000). It appears to be more specific than taxol, the anti-cancer agent extracted from *Taxus baccata*, the common yew. There may also be a role for betulinic acid in the treatment of HIV (De Clercq 1999). If these studies prove successful in trial there may be a pharmaceutical market for birch bark in the future.

Birch research abroad

The idea of carrying out research on native birch improvement is a relatively new departure for Ireland. Some provenance trials were established by Coillte in Spring 1999 using 45 provenances of Scottish *B. pendula* (supplied by the UK Forest Service), one home-collected *B. pubescens* source, and two Finnish and four Swedish observation plots. A small 15 year old trial, including Finnish and Irish *B. pubescens*, was established in Kilmacurragh (Table 3). The birch trees lining the front of the Teagasc research centre at Kinsealy are derived from a clone of micropropagated *B. pendula* from Sweden, produced as part of the COST-822 Woody Plant Group joint research project. Ireland is currently involved, through Dr Tommy Gallagher of UCD Botany Department, in an EU project (FAIR5-CT98-3823) aimed at improving the wood quality of *B. pendula*. Using a biotechnological approach, they are characterising and validating wood properties in birch for industrial use and future breeding. To date, AFLP markers linked to traits such as stem straightness, branch number and branch angle have been established.

Several other European countries have recognised the economic importance of birch and already have improvement programmes in place. These are summarised below:

Table 3: Summary of performance of two trials of foreign birch in Ireland assessed in 1998.

Site	Species	Age (years)	Origin	Tallest individual (m)	DBH (cm)	Survival (%)
Comeragh Forest	*B. pendula*	32	Sweden A	12.5	8.1 ± 0.9*	53
	B. pendula	32	Sweden B	17.0	9.2 ± 1.4	53
Kilmacurragh**	*B. pubescens*	14	Ireland	10.5	10.3	100
	B. pubescens	14	Finland	10.3	10.2	69
	B. pendula	14	Finland3	12.0	10.0	22
	B. pendula	14	Finland6	8.0	7.9	6

* standard error
** data supplied by Coillte, standard error not available

Finland:
Finland has the most advanced birch improvement programme in the world and the knowledge and techniques developed are applicable to the Irish programme. Birch was common on the Finnish landscape because of the slash and burn agriculture practiced into the 19th century. When this practice ceased, birch was no longer able to regenerate so freely and by the end of the 1950s it became apparent that most birch stands were ageing and not regenerating. In 1960, the value of this species was recognised and a birch improvement programme was launched by the Foundation for Forest Tree Breeding (FFTB). It should be noted that on the occasion of the 50th anniversary of the FFTB in 1997, number one in the list of 'ten most esteemed achievements of the Foundation' was the programme for breeding and seed production of birch. To put this in context, the establishment of 3000 hectares of conifer seed orchards came fifth.

Birch phenology is very strongly linked to temperature sum and photoperiod. Because Finland spans from 59.50ºN to 70.03ºN latitude the growing period (daily mean temperature above +5ºC) ranges from 180 days in the south to 110 days in the extreme north. It was therefore necessary to breed separate groups of trees for the north, centre and south of the country using four seed zones. A total of 1872 *B. pendula* and 619 *B. pubescens* individuals of superior phenotype were selected as the base for an improvement programme. Emphasis has been largely on progeny trials although some provenance trials have also been established. Genetic gains have been reported in terms of stem volume, diameter, height, reduced taper and relative branch thickness. Stem volume increases of over 40% have been achieved in some progeny trials (Raulo and Koski 1977). Highly relevant to the Irish improvement programme is the discovery that fast growth does not compromise quality of form. More recently, birch improvement research has ventured into new areas such as browsing resistance (Rousi *et al.* 1996); insect resistance (Mutikainen *et al.* 2000); wood quality (Tammisola *et al*. 1995); genetic transformation (Valjakka *et al.* 2000); DNA markers (Akerman *et al.* 1995, Welander *et al*. 2000); pollen performance (Pasonen *et al*. 1999); and birch sterility (Lemmetyinen *et al.* 1998).

Currently 17% of new Finnish forest plantations are birch. In 1997, *B. pendula* composed 12% of total tree nursery production and *B. pubescens* composed 2%. This amounted to 16 million *B. pendula* and 2.6 million *B. pubescens* plants. Of these, 82% of *B. pendula* and 33% of *B. pubescens* plants were produced from genetically improved material from indoor seed orchards (FFTB - unpublished data). The Finns report up to yield class 10 for birch at 2 x 2 m spacing. Improved material has rotations of 40 years and produce over 400m^3/ha (Vihera-Aarnio 1994).

Germany:
The German birch improvement programme started in 1955 has resulted in approximately 50% stem volume increase (Kleinschmit 1999). Some 200 *B. pendula* and 50 *B. pubescens* plus trees were selected. Provenance tests were set up, incorporating German, Dutch, Polish, Finnish and Swedish material. Five progeny tests involving 15 sites have also been established. Of interest to Ireland is that *B. pubescens* performed better than *B. pendula*, despite selecting sites which favour the latter. Progeny from *B. pubescens* derived from seed orchards give the best growth and form (Kleinschmit 1998). Clonal material is produced using *in vitro* micropropagation techniques. Hybrids between *B. platyphylla japonica* (an American species) and *B. pendula* demonstrate

volume production which is double that of *B. pendula*. Currently only 1% of German forest planting is birch. As in the Finnish programme, the Germans have found that fast growth can be congruent with stem quality.

United Kingdom:
Some plus tree identification was carried out in the UK in the 1950s. In 1979 progeny trials were established at Craibstone, Aberdeen, with material from 80 plus trees selected from north east Scotland and 20 plus trees from England, Scandinavia and continental Europe. In 1984 diallele crosses were carried out between five phenotypically superior individuals from this trial. These are currently under trial along with 12 half-sibling progeny trials. Seed was collected from 40 of the original 1700 trees and a seed orchard was established from grafts. Further trials in the early 1980s found family differences for height and die-back resistance. The UK birch improvement programme has been revived as the Birch Research and Development Co-operative and in spring 1997 trials of forty *B. pendula* and five *B. pubescens* provenances were planted out. This trial is being replicated on three sites in the UK and some material has been planted out on a Coillte site near Mallow, Co Cork. Seven Scottish provenances from these studies will also be included in this project. There are currently four registered *B. pendula* seed stands in the UK. An untested clonal seed orchard based on Scottish material is being revived at the Forestry Commission's Northern Research Station (Anon. 1999).

Belgium:
There is a large research project at Geraardsbergen Institute for Forestry and Game Management to examine the soil water and nutrient changes following transformation of even-aged pine-stands into uneven-aged broadleaf forest, primarily *Betula* and *Quercus* (De Schrijver *et al.* 2000). Some work on birch regeneration is also being carried out by this group. There are no officially registered birch provenances (Dr Kris Vandekerkhove - pers. comm.) but a Belgian birch selection programme commenced in 2001 at Geraardsbergen Institute.

Why improve Irish birch?

One of the most commonly asked questions during this project has been "Why don't we just import quality seed from abroad?" This has been attempted on several occasions with poor results (Table 3). The major reason for the failure of imported birch to perform under Irish conditions is that the plants are not adapted to the local climate and environment. Birch is highly sensitive to local seasonal changes in temperature and photoperiod (Myking and Heide 1995) and climatic ecotypes evolve along gradients of altitude and latitude. For example, there is a well-documented north-south trend of birch ecotypes where southern populations require a shorter day-length to induce dormancy (Håbjørg 1978, Myking 1997). By moving birch southwards from a northerly origin they will flush earlier in the season than the local birch and may be damaged by late frosts and chill or drying winds. Recently, Worrell *et al.* (2000) advised against planting Scandinavian material in the UK for these reasons. Conversely, by moving birch northwards from a southerly origin they will become dormant later in the season than the local birch and may be damaged by early frosts and chill or drying winds. Over several seasons, trees may lose vitality and even die. This is why birch in Finland is bred for different zones.

Because birch is relatively sensitive to day-length and temperature sum, there is an argument in favour of planting locally derived material as it is believed to be locally adapted. However, local provenances may not always be the fastest growing trees (Worrell 1992). In fact, it has been frequently noted that trees moved from southerly regions achieve faster growth rates than the local population due to the longer days during the growing season. Such observations may be due to the fact that local trees are not optimally adapted but, instead, lag behind the changing environment (Lynch and Lande 1993). Ideally, genecological studies should be established to examine a geographic range of populations on a geographic range of sites. Such studies are used to identify seed transfer guidelines and to identify sources of faster growing trees (Aitken and Hannerz 2000). Such a study is currently being carried out with *Betula papyrifera* Marsh in British Columbia (Simpson *et al*. 2000). Velling (1979) describes the initial growth of fifteen *B. pendula* provenances from a range of latitudes (56º C 31' N to 61º C 48' N) tested on three south Finland sites. The drawbacks of long-distance transfer only become apparent when the shift of origin exceeds a certain distance or altitude. Langhammer (1981) recommends that material

should be shifted no more than ± 3º of latitude, while Worrell (1992) suggests a maximum of 4º of latitude. Provenances from further south but from higher altitudes may also be regarded as a potential source of planting material as an increase in elevation is equated with an increase in latitude. For example, in Norway an increase in elevation of 100 m is considered equivalent to an increase of 2 to 3º latitude (Skinnermoen 1969).

In order to produce Irish birch with commercial potential it is necessary to develop a selection and improvement programme to identify sources of birch which will produce quality stems with a reasonable productivity. Previous attempts to grow Finnish and Scandinavian trees in Ireland yielded poor results. Two Swedish provenances planted in 1966 at Comeragh Forest show very low survival rates (47%) and poor growth (Table 3). Growth, estimated as mean diameter at 1.3 m, was not significantly different between the two provenances (independent samples t-test, 2-tailed sig. = 0.49, 95% confidence level). These trees have very thin canopies with a large amount of die-back. This is a typical scenario when birch is moved too far south from its point of origin. The Finnish trees at Kilmacurragh are displaying similar poor survival and growth with thinning of the canopy. Table 4 shows a similar pattern observed in a Scottish provenance trial testing local, Finnish and Norwegian provenances. These results do not suggest that foreign birch material should be dismissed. It does suggest that any foreign material brought into Ireland for forestry planting should be carefully selected and tested (note that this is not a native gene conservation project, it is a project with a remit to identify birch with economic potential and, thus, foreign material should be considered). For Ireland it may be worthwhile testing *B. pendula* and *B. pubescens* from similar latitudes, e.g. Scotland, UK, the Netherlands, Belgium, north Germany, Denmark and, perhaps, southern-most Sweden.

Table 4: Summary of performance of *B. pendula* provenance trials in Speymouth, Scotland.

Origin	Top ht (m)	DBH (cm)	Survival (%)
Finland	6.2	5.2	36
Norway	5.4	5.1	50
Scotland	8.4	10.4	94

Data supplied by R. Worrell

Birch Selections

Following a literature review and initial field observations, the definition of a 'quality' birch was outlined as: 'A single, persistent, cylindrical, lightly-branched stem without kinks, fluting, disproportionately-large branches or clusters of epicormic buds'.

The Coillte birch inventory was consulted and a series of fliers was sent to approximately 100 Coillte personnel, woodland owners, Teagasc forestry advisors, private forestry consultants, park rangers, environmental researchers and bird and wildlife professionals, requesting information on the presence of birch in their area. These actions were backed up by a telephone survey. Further advertising of the project and requests for information from interested parties were made through newsletters and newspapers (Irish Timber and Forestry, Releafing Ireland, The Irish Scientist Year Book 1998, the Irish Times, Foinse, and COFORD Forestry and Wood Update). The Northern Ireland Forest Service carried out a birch survey on our behalf, and this identified eight potential quality birch populations. Figure 2 presents the location of sites from which 'quality' birch trees were eventually selected.

Selecting populations

The general form of the seven planted stands surveyed was very poor in terms of straightness, fluting and forking (Comeragh, Kilmacurragh, Roosky, Bunclody, Glanmore, Rathdangan and Clonsast). Instead, attention was largely concentrated on naturally regenerated stands. It is difficult to estimate the number of trees surveyed in this project as sites ranged in size from one tree to several hectares of trees. Birch populations ranged from >95% birch to scattered individuals within conifer or mixed stands. Survey intensity varied from simple overview to measured plots within better quality

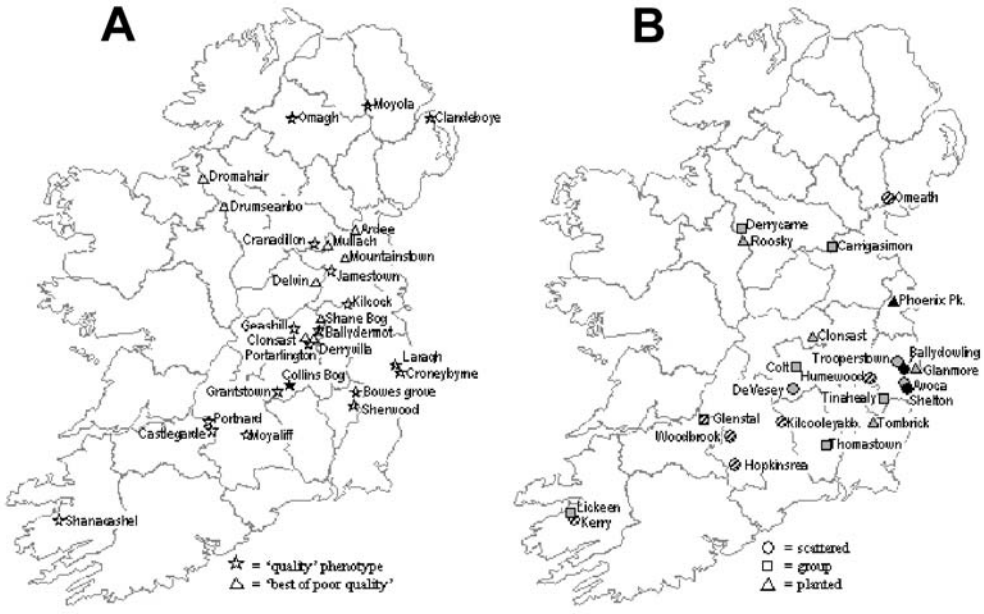


Figure 2: Location of sites sampled to date. Map A shows sites in which birch was the dominant species. Map B shows sites where birch was scattered (<5%) through the site or occurred only as a small group (<50 trees). All sites were deemed to be naturally regenerated unless shown otherwise. Black symbols = *B. pendula*; grey = *B. pubescens*; striped = both species present.

sites. All trees were individually observed in stands where the average diameter at 1.3 m exceeded 12 cm. Sixty such sites were recorded.

There was no information available on the history of the stands examined. Furthermore, there is limited information about which birch form characteristics have a strong genetic component, although Blackburn and Brown (1988a) state that early height growth and resistance to die-back are under a strong genetic control in UK *Betula*. In addition, Kennedy and Brown (1980) assert that there is a positive relationship between smooth-peeling bark and fast growth. Current studies are providing evidence to suggest that form characteristics such as relative branch diameter and branch frequency have a genetic component (Welander *et al*. 2000). Given the poor form of most populations it was difficult to use conventional mensuration techniques to compare the relative quality of stands. So, following an initiation phase of birch observation, a list of desirable and undesirable traits was compiled. A simple qualitative scale (very poor, poor, moderate, good, very good) was then used to describe many of the observed traits. A method of generating quantitative data from qualitative data was examined using a weighted scale for the different traits with adjustments to account for stand density and exposure (O'Dowd 1998). This allowed comparisons to be made between stands but was time constrained and remained highly subjective.

Populations with repeatedly observed positive traits were designated as 'superior stands'. Seed was collected from superior populations. The collection of seed which was representative of provenances/ populations proved to be difficult. Given the limited resources for field testing the seed collection, it was decided to collect only trees of good to moderate form. On many sites trees of moderate form were scarce so only a small number of trees were collected from these sites (see section 'Collection of Birch Seed'). Identification of selected trees was carried out in 1998 and 1999 and the seed collection was made in 1999. Because of the small number of trees representing most provenances, the field trials were established as a series of progeny trials rather than provenance trials, although the provenance from which each tree is derived can still be traced.

Selecting individuals

Trees possessing all of the specified 'quality' characteristics are rare. As a result it was necessary to select individual trees that satisfied most of the criteria listed in the definition of a quality birch. On several sites it was a case of selecting the 'best of a poor population' (Figure 2A), otherwise many regions would not be represented in the collection.

Standard recording sheets for site, soil and tree data were designed during the initial observation phase once an indication had been obtained of the distribution and quality of Irish birch being dealt with. Details of superior phenotype individuals were recorded on these sheets and the data entered into a database.

The criteria for assessment were:

1. Must have:
   - single, straight, cylindrical stem (reject if coppiced)
   - minimum diameter at 1.3 m of 15 cm
2. Reject if any of the following traits are present:
   - fluting
   - more than one disproportionately large branch present
   - forked below 7 m
   - vertical occlusions present after self-pruning
   - clusters of epicormic buds present
   - acute angle of branch insertion
   - retention of snags after self-pruning
3. Tree details included:
   - height and diameter at 1.3 m (dbh)
   - estimated age
   - kinks (number and height); leader loss height; stem straightness; taper and sweep (good, moderate or poor); lean
   - bark colour; bark peeling (easy, medium, difficult)
   - branch frequency, size and angle
   - crown shape (narrow, medium or spread)
   - damage (mechanical, insect, browsing or disease)
   - additional notes and samples taken (leaf, twig and/or seed)
4. Site details included:
   - national grid co-ordinates; owner details
   - altitude; exposure; slope and aspect
   - general vegetation description
   - rating of general birch form (very poor, poor, moderate, good, very good)
   - site origin (natural regeneration or planted)

5. Soil details included:

- soil classification, soil association
- topography, drainage, parent material
- soil horizon; horizon depth, description and pH

Branch angle was assessed but due to the high stocking of unmanaged, natural stands, this information is of little value.

Within naturally regenerated stands it was sometimes possible to observe clusters of trees of similar phenotype but which were phenotypically distinct from the surrounding trees. It was speculated that these groups may represent families, as birch seed does not generally travel far from the mother tree (Sarvas 1948) and the groups were distinctly different in phenotype to surrounding trees. This grouped distribution of characteristics suggests that they could be, at least in part, genetically determined. If so, this would allow such traits to be selected for or against. The 'best' individuals from clusters with desirable traits were selected. Table 5 lists traits commonly observed within such clusters.

Table 5: Phenotypic traits observed within clusters of trees in naturally regenerated stands. Some traits were favoured and others discriminated against during birch selection.

Trait	Status
Cylindrical stem	selected
Presence of fluting	not selected
Flattening/squaring of stem (non-directional)	not selected
Presence of disproportionately large branches	not selected
Vertical occlusions after self-pruning	not selected
Presence of clusters of epicormic buds	not selected
Stem colour	selection neutral
Acute angle of branch insertion	not selected
Retention of snags after self-pruning	not selected
Prominent branch bark ridges	not selected if associated with stem deformation

The birch database

A database was created to manage data on individual birch of quality phenotype. This database can be accessed through COFORD. Information on site, soil and tree characteristics were input and can be examined to look for trends. Details on 44 superior phenotype individuals are included. National grid co-ordinates for each dataset are included so that information can be spatially presented by exporting information from the database to a geographic information system (GIS) application, e.g. Arcview. For example, this method was used to construct Figures 2A and B. By the use of queries it is possible to present specific data in tabular or map form, e.g. sites with a pH of less than 5.0 occurring below 100 m or *B. pubescens* sites on a specified soil association.

Originally, the database was to contain information on individuals of superior phenotype. This imposed limits upon its size and usefulness. The database was therefore adjusted to include information on stands and groups of trees of interest irrespective of quality. A total of 117 sites have been input and this needs to be expanded. Information on a database of Scottish native trees was published recently (Wilson *et al.* 1999), describing a similar scenario for *B. pubescens* as encountered in Ireland and outlining the difficulties experienced in recording a species with an 'essentially continuous distribution in many regions'. Their solution is to recognise small catchment areas rather than discrete stands. This method supports the approach taken by this project.

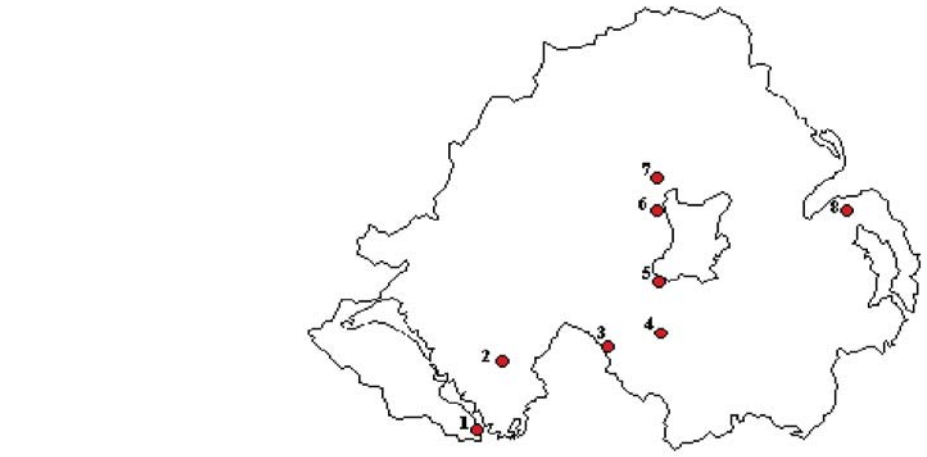
Location of birch stands

It should be noted that these are initial observations and that some parts of the country have yet to be investigated. Figure 2 gives an impression of the areas covered and reflects the fact that areas of Connacht and Ulster have yet to be examined in depth. The Northern Ireland Forest Service, DANI, identified eight Northern Irish birch sites (Figure 3) and the two most strongly recommended were visited (Moyola and Clandeboye). Two additional Northern Irish sites were sampled near Omeath and Omagh.

Birch distribution

Stands of mature birch greater than 0.5 hectares were less common than anticipated. Most of the quality mature birch occurs in the eastern half of the country although this picture has yet to be completed (Figure 2A). Mature trees were more commonly found in small groups of less than 50 trees or as scattered individuals in an area (Figure 2B). There were no reports of quality birch from contacts in Mayo, Galway, Roscommon or Clare and this was supported by observations in the field by the authors and by the Teagasc FIPS-IFS group[6] during their field studies. Birch was scarce in Waterford and Wexford.

Another pattern that emerged was that *B. pendula* is relatively uncommon throughout the country. This



Site No.	Name	County	Soil Type*	Elevation (m)
1	Crom castle	Fermanagh	SWG2	60
2	Colbrook Estate	Fermanagh	Deep peat	70
3	Carnagh	Armagh	Deep peat	160
4	Gosford	Armagh	SWG2	70
5	Peatlands Country Pk	Armagh	Deep peat	20
6	Drumconvis	Tyrone	Deep peat	30
7	Moyola	Londonderry	Deep peat	30
8	Clandeboye	Down	BR C	70

Figure 3: Location of potential quality birch sites identified by the Northern Ireland Forest Service. (*SWG2 = surface water gley).

may be a reflection of the poor sites upon which birch generally occurs. Many sites were on peat soils and often suffered poor drainage. In such conditions, *B. pubescens* may out-compete *B. pendula* where the species co-occur. The lack of *B. pendula* in Scotland is discussed by Worrell and Malcom (1998) and their findings may also be applicable to *B. pendula* growing in Ireland. They attribute the scarcity of *B. pendula* on the west coast of the highlands of Scotland to a variety of factors such as:

- its need for free-draining soil;
- its inability to persist on intensively farmed landscapes;
- its inability to persist as woodland understorey;
- its difficulty in regenerating on grass sward;
- lack of disturbed ground for colonization;
- its short life-span.

Birch was found growing over a wide range of soil conditions. Rackham (1980) could find no relationship between soil pH of ancient woodland in eastern England and the incidence of birch. Atkinson (1992) suggests that both species tolerate a wider range of soil pH than is usually ascribed to them. We found that it was difficult to correlate soil type and occurrence of birch although soil association 44 (basin peats) was frequently noted to support birch populations. This probably reflects human interference rather than species preference. Seventy-eight percent of naturally regenerated populations recorded occurred on peat or peaty soils. The most acidic site recorded was a poorly drained peat with a topsoil pH of 3.8 and subsoil pH of 3.7 (Portnard). The most alkaline naturally regenerated site recorded was a well-drained peat on limestone with a topsoil pH of 5.8 and subsoil pH of 7.6 (Athboy). The most alkaline planted site recorded was at Clonsast with a topsoil pH of 7.4 (0 – 40 cm) and subsoil pH 8.1

Managed birch sites

It was noted that several sites that were deemed to be naturally regenerated were being managed to various degrees and it will be interesting to monitor the development of these stands:

Ballydermot: Mixed broadleaf woodland thinned to select trees of best form including birch.

Colt: ~0.5 hectares of respaced birch.

Cranadillon: Thinned birch woodland, aim unclear.

Humewood: Site cleared to leave ~10 m high birch at wide, variable spacing, underplanted with ~3 year old oak and ash.

Shanacashel: Coillte site with ~0.5 hectares of birch which encroached on Sitka spruce, spruce removed and birch respaced in 1998.

Tullaghan: ~ 1 hectare with ~20 year old birch thinned and pruned.

Bowe's Grove: Mixed birch, Sitka spruce, beech and minor species woodland. One of the best birch stands observed in this study in terms of quality. Thinned in 2000 to leave best birch stems.

Planted birch sites

Several sites were examined which were deemed to have been planted. With the exception of the Phoenix Park site, none of these have performed particularly well:

Bunclody: 2 hectares of birch of local origin (Tomduff). Single stems moderate to poor quality.

Glanmore: approximately 70 individuals planted as amenity. Several with moderate form but disease may be a problem.

Kilmacurragh: Blocks of Finnish, Swedish and Irish material, 14 years old in 1998 (see Table 3).

Clonsast: Several hectares of poor *B. pubescens* planted at 1.5 m spacing on cut over peat. Occasional good quality stems.

Rathdangan: German material planted in mixture with conifers. Only a few poor-quality stems remain and planting notes too vague to be useful.

Occasionally, birch can be observed as forest edge landscaping, e.g. Lough Caragh, Kerry, and Roosky in Leitrim, but quality tends to be poor.

Observations on birch growth

Trees selected for superior form were also measured for height and diameter. The tallest trees measured were two 100 year old planted *B. pendula* individuals in the same population (Phoenix Park) which stood at 26 m and 24.5 m. Apart from a specimen of *B. pubescens* from Wexford with a dbh of 43 cm, these two also had the largest girths recorded (41 and 37 cm, respectively). The tallest *B. pubescens* recorded was 23 m, a specimen growing beside Sitka spruce at Trooperstown, Wicklow. These are all sheltered sites and this may have assisted the development of persistent leaders.

The mean height : diameter ratio for both species was similar, i.e. *B. pendula* was 80 ± 20 cm high per 1 cm diameter (dbh) while this figure was 80 ± 17 cm for *B. pubescens*. More trees need to be measured on a variety of sites before these preliminary observations can be confirmed as this observation is based on only 9 *B. pendula* and 31 *B. pubescens* individuals. It would also be useful to know the age of trees being measured, but with the exception of the Phoenix Park trees (100 years in 1998), the age of trees was unknown.

6 Forest Inventory and Planning Systems - Irish Forest Soils project based in Teagasc, Kinsealy, and funded by the Irish Forest Service (1998-2002).

Collection of Birch Seed

Seed was collected in August-September 1999. A collection was made of 27 *B. pubescens* and 16 *B. pendula* provenances, representing a total of 94 *B. pubescens* and 27 *B. pendula* families (Table 6). These trees were located on the 30 'best quality' sites of the 60 sites examined in detail with 1 to 10 ten trees sampled per site. Six additional sites could not be sampled as the seed was inaccessible but revisiting to collect by shotgun should be considered. Additional seed was collected from a single *B. pendula* individual planted at UCD and a further four *B. pendula* families were collected from a plantation in the Phoenix Park (all of unknown origin but superior phenotype).

Twelve percent of trees sampled bore no seed. This is not uncommon where the tree is surrounded by dense woodland (Worrell 1999). Edge trees generally yielded most seed but their form was generally poorer (this reflects environmental influences, it does not suggest that edge trees are necessarily of poorer genetic stock). Quantities of seed harvested from individual trees ranged from 0.1 to 336 g (seed + bract dry weight @ 7.5% moisture content). Worrell (1999) estimates 1 to 3 million seeds per kilogram. Twig samples were taken from each seed tree and the inner bark used in a colorimetric test to identify the tree species (Lundgren *et al*. 1995).

Traditional sampling methods for provenance trials used at the University of British Columbia Department of Forest Sciences (Sally Aitken - pers. comm.) recommend that:

- 10 to 25 bulk seedlots make up each provenance;
- sampling locations are selected using a systematic grid, by sampling according to climate or soil types, or with sampling density adjusted according to natural abundance;
- individual parent trees should be separated by >100 m to minimize relatedness;
- each tree contributes equally to the seedlot.

For this study, most sites were too small to apply these rules but a minimum distance of 30 m was used wherever possible. The distance between seed trees on the same site was recorded. Seed was collected from different areas of the canopy in order to reduce the probability of collecting seed with the same paternity. Seedlots were sown separately and the seedlings were then bulked to form provenances in order to ensure equal contribution of each family.

Seed was also acquired from the UK, Germany, France, Sweden, Poland and Iceland. The Irish Forest Service stated that no foreign material should be included on grant-aided birch sites so, with the exception of Scottish material, these trees were discarded, except for those to be planted on the peat site at Boora which belongs to Bord na Mona and which is not grant-aided.

This study has not been exhaustive and it is anticipated that further superior populations and individuals will be discovered in the future.

Eight populations were sampled, irrespective of quality, because they were considered to be under threat from human activity or lack of regeneration and the researchers wanted to preserve samples from these sites. Table 7 lists those sites noted in the birch database that were considered to be under threat.

Seed was collected, air-dried for 2 to 3 weeks in brown envelopes, sieved and cold-stored at 0ºC in sealed plastic containers. Seeds with small wings were separated from bracts by sieving. Large-winged seeds were difficult to separate from bracts by this method so separation was not generally carried out on such samples. Germination trials using a series of stratification protocols were established in December 1999 from three seedlots to estimate viability and to establish a dormancy-break protocol for future sowing. Sowing for field tests was carried out in Spring 2000 following stratification.

Table 6: Sites from which seed was collected from birch of good to moderate quality phenotype. Shaded rows indicate best quality sites.

Site name	No. seed trees*	General form	Stand description	Species (2,4-DNPH)	Stand Size**
Ballydermot	1 + (3)	good to moderate	nat. regen. mixed woodland	both	P
Bowes Grove	5	very good	nat. regen. mixed woodland	*B. pubescens*	P
Butlersbridge	3	poor	nat. regen	*B. pubescens*	P
Clandeboye	1	v. good to moderate	nat. regen. mixed woodland	both?	P
Collin's Bog	2 + (2)	good	nat. regen. in conifer	both	P
Colt	(3)	good	edge of Sitka plantation	*B. pendula*	G
Crannadillon	4	moderate, occ. good	nat. regen	*B. pubescens*	P
Geashill	2 + (2)	moderate to poor	nat. regen.	both	P
Glanmore	4	moderate to good	planted, origin unknown	*B. pubescens*	G
Devil's Glen	(1)	v. poor	nat. regen.	*B. pendula*	S
Grantstown	2 + (2)	moderate, occ. good	nat. regen in mixed woodland	both	P
Hopkinsrea	4 + (1)	poor to moderate	nat. regen in conifer	both	P
Humewood	6	good	clearfell leaving birch	*B. pubescens*	G
Kerry	4 + (1)	moderate	nat. regen.	both	S
Kilcock	3 + (1)	moderate	nat. regen., some alder	both	P
Kilcooleyabbey	2 + (1)	moderate	nat. regen. mixed woodland	*B. pendula*	S
Laragh	6	moderate	nat. regen.	*B. pubescens*	P
Lickeen	2	moderate	nat. regen?	*B. pubescens*	G
Mountainstown	4	v. poor to moderate	nat. regen.	*B. pubescens*	P
Moyaliff	3 + (1)	good	nat. regen.	both	P
Moyola	4	moderate to good	nat. regen.	*B. pubescens*	P
Mullach	3	poor to moderate	nat. regen., very wet site	*B. pubescens*	P
Omagh	6 + (1)	moderate	nat. regen.	both	P
Omeath	1 + (5)	moderate	nat. regen.	both	S
Park_Hotel	(1)	poor	nat. regen.	both	P
Phoenix Pk.	(5)	good	plantation	*B. pendula*	G
Portarlington	9 + (1)	good to moderate	nat. regen., pure birch	both	P
Shane_Bog	1 + (1)	poor	nat. regen.	*B. pubescens*	P
Sherwood	4	poor to moderate	nat. regen., very wet site	*B. pubescens*	P
Tinahealy	5	good (tends to flute)	nat. regen.	*B. pubescens*	G
Trooperstown	4	moderate	nat. regen. in conifer	*B. pubescens*	S
UCD	(1)	good	planted, origin unknown	*B. pendula*	I
Total:	98 + (32)				

* numbers in parentheses denote number of *B. pendula* sampled on a site.

** P = sites with *Betula* as dominant species in, at least, part of the site; G = groups of <50 trees; S = birch scattered, composing <5% of species on the site; I = only one *Betula* individual at site.

Table 7: Birch populations considered under threat from human activity. Representative seed samples were collected from these sites irrespective of stand quality.

Site	Status	Species
Ardee Red Bog	Only small area remaining	*B. pubescens*
Ballydermot Bog	Partial clearance for Europeat powerlines	Both
Butler's Bridge	To be cleared for by-pass road	*B. pubescens*
Derryvilla	Coppiced in 1998	*B. pubescens*
Kilcooleyabbey	To be felled	Both
Phoenix park	Declining, no regeneration (102 years old)	*B. pendula*
Portarlington	Partial clearance for powerlines, no regeneration	Both
Shane Bog	Only small area remaining after clearance	*B. pubescens*

Grafting of Quality Birch

An indoor seed orchard/gene bank was established in a cold greenhouse with grafted plants of selected birch. The seed orchard was to produce seed of known parentage for testing in order to obtain information about genetic parameters of Irish birch growth, supplemental to the information to be obtained from the open pollinated material. Scion wood was collected from birch trees which were deemed phenotypically superior during Winter/Spring 1998 and 1999. Scions were held at 0ºC until February when side-whip grafts were prepared onto 60 to 90 cm bare-rooted *B. pendula* and *B. pubescens* rootstocks (root collar diameter of 4 to 10 mm). The entire scion and graft union was waxed. Grafted plants were potted up in 2 litre (L) pots in peat-based compost supplemented with 4.7 g/L 12-14 Osmocote slow-release fertilizer and 1g/L suSCon® Green pesticide to control vine-weevil larvae (*Otiorhynchus sulcatus*). Grafts were nursed in a cool, shaded greenhouse. Between 8 and 80 grafts were initiated per parent tree, depending on availability of healthy scion material. Variable scion sizes were used. Scions with male catkins or 'short shoots' were included in a series of experiments. Short shoots are birch buds which bear female catkins and are morphologically distinct from vegetative buds (Maillette 1982). A total of 12 *B. pendula* and 33 *B. pubescens* individuals were grafted onto ~1800 rootstocks over the two grafting seasons.

Results

Grafts began flushing five weeks after grafting and survival rates varied from 0 to 100% (Figure 4). Survival rate is a product of many factors including clonal variation, health of plant material and grafting technique. Health of rootstock was important as clones #7 (*B. pendula*, Avondale) and #25 (*B. pubescens*, Roosky) showed signs of die-back in the scionwood and both failed to graft. All clones with a graft survival rate greater than 20% grafted successfully onto both species of rootstock.

The inclusion of suSCon Green in the substrate proved necessary as it was noted that trees aged up to one year suffered larval attack to the roots causing plant death where suSCon Green was not refreshed in the medium. Leaf damage by adult vine weevils was also observed on grafted birch.

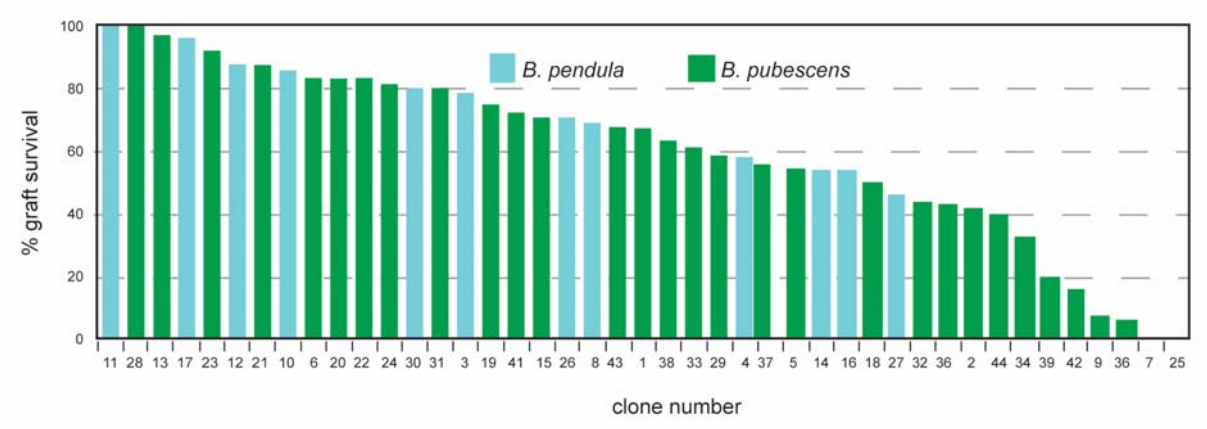


Figure 4: Percentage survival of *Betula* grafts four months after grafting.

Grafts achieved mean heights of 123 ± 20 cm and 199 ± 28 cm for all clones after one and two growing seasons, respectively. Data were first tested for normality. A one-way analysis of variance was then used to test the difference in height between each pair of a group of clones one year after grafting. Tukey's pairwise multiple comparison test inferred that clones #37, 32, 33, 50, 38, 36 and 41 were significantly taller than the *B. pendula* clone #43. Table 8 shows homogeneous subsets of clones determined by height and based on mean differences, significant at the 0.05 level. A similar analysis of a different group of two year old grafted clones (Table 9) ranked the growth performance of clones but did not support the implication that *B. pendula* grafts may be slower growing than *B. pubescens* grafts. In fact, from this

Table 8: Results of Tukey's pairwise multiple comparison test on heights of one year old grafts, showing homogeneous subsets of clones.

Clone	n**	Mean height (m)	s.e.	Subset for alpha = .05 (Tukey's HSD)			
43*	51	110.29	3.75	a			
34	22	111.95	5.32	a	b		
44	23	113.96	1.40	a	b	c	
41	43	124.40	2.24	a	b	c	d
36	16	125.69	4.50	a	b	c	d
38	34	125.94	2.63	a	b	c	d
50	30	128.07	5.69	a	b	c	d
33	35	129.14	2.68		b	c	d
32	16	130.00	3.71			c	d
37	27	132.41	3.03				d
Sig.				.051	.069	.120	.920

* *B. pendula*
** Sample sizes different; harmonic sample size used = 25.96

Table 9: Results of Tukey's pairwise multiple comparison test on heights of two year old grafts, showing homogeneous subsets of clones.

Clone	n	Mean height (m)	s.e.	Subset for alpha = .05 (Tukey's HSD)			
16*	6	170.0	5.47	a			
6	14	178.6	4.26	a	b		
5	6	183.5	6.88	a	b	c	
30	6	183.8	6.49	a	b	c	
15	7	188.1	5.87	a	b	c	
13	19	189.4	4.97	a	b	c	
20	7	190.7	8.25	a	b	c	
14*	11	192.3	5.40	a	b	c	d
1	11	193.2	4.44	a	b	c	d
2	5	194.8	6.64	a	b	c	d
12*	18	195.4	5.13	a	b	c	d
10	9	197.0	9.77	a	b	c	d
3*	12	197.8	8.31	a	b	c	d
19	11	202.6	7.13	a	b	c	d
17*	8	213.1	9.23		b	c	d
23	6	215.3	5.87		b	c	d
31	6	217.3	8.41			c	d
28	11	218.6	7.70			c	d
4*	8	220.5	12.27			c	d
11*	20	228.8	3.34				d
Sig.				.194	.067	.061	.070

* *B. pendula*
** Sample sizes different; harmonic sample size used = 8.37

group, the tallest grafts were from *B. pendula* clone #11, which was significantly taller than seven of the other 19 clones.

Differences in form began to appear in the second year. Several clones exhibited strong apical dominance (clones #4, 11, 17, 23, 24, 28 and 31[7]). Others demonstrated tendencies towards leader loss (clones #26 and 50), leader retardation or suppression (clones #6 and 29) or disproportionately large branches (clones #3 and 4). It will be interesting to follow these traits in the grafts and in their progeny.

Scions were sampled at a height of 8 m. Samples from small trees were therefore taken from live crown while taller trees were sampled from the lower crown. Figure 5 compares 1998 graft survival and tree height, following exclusion of results from trees with visible dieback, all of which failed to graft. Free-standing trees were also excluded as only enclosed canopies were being studied. *B. pendula* is shade-intolerant and shaded branches will eventually die. By sampling lower branches of tall *B. pendula* individuals in a closed canopy situation there is a risk of sampling non-vigorous material. This may in part explain the strong (i.e. $r > -0.3$) linear negative correlation between tree height and graft survival shown in Figure 5A. *B. pubescens* is more shade-tolerant and can retain living branches in the lower canopy. This may explain why the correlation between tree height and graft survival is weaker for this species (Figure 5B). It would be necessary to sample individual trees at different heights to confirm these observations.

There appeared to be clonal differences in pest infestation. Several clones suffered severe greenfly (*Euceraphis betulae*) attack (clones #9-14, 16 and 17) while other clones nearby were unaffected (clones #23, 24 and 26). Remaining clones suffered moderate levels of infestation. It was not tested whether these patterns were due to resistance in birch. Nonetheless, it was interesting to note that six of the eight heavily infested clones were *B. pendula*, although one of the three unaffected clones was also *B. pendula.* Rousi *et al*. (1997) found that fast growth does not compromise resistance, so selecting for pest resistance may be of interest in future Irish birch research and resistant individuals should be recorded.

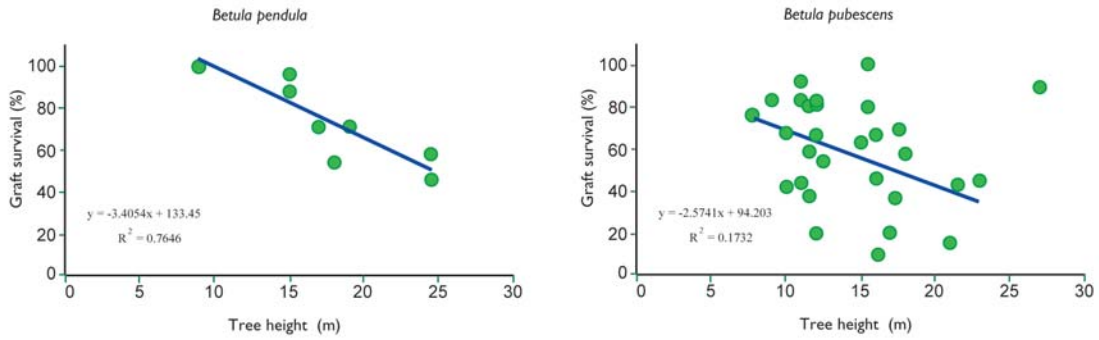
Scions with male catkins died unless the catkin was fully waxed during the grafting process. The most likely explanation for this is that scion desiccation occurred via the catkin. Scions with waxed male catkins had a comparable survival rate to scions without male catkins. Waxing did not impede catkin development and pollen release. Some grafted plants produced male catkins in early June and these over-wintered normally, eventually producing viable pollen the following summer. This pollen was used fresh to carry out controlled crosses in 1999.

Scions with short shoots commenced female flower production five weeks after grafting (Figure 6). These flowers were used in controlled pollinations to produce seed. Some clones grafted in 1998 produced male and female catkins in 1999. It was not possible to predict flowering in the second growing season based on results from the first season (Table 10). The observed rhythm of flowering did not support the phase-change model encountered with most broadleaves. Grafting broadleaves can rejuvenate the scion, removing its capacity to flower. This did not happen with birch in this case. In 2000, all clones produced male and female flowers.

Table 10: Female catkin production from 27 clones of grafted birch (grafted in 1998).

Female catkin production	No. of clones
None in ’98 or ‘99	9
Catkins in ’98 but not ‘99	5
Catkins in ’99 but not ‘98	6
Catkins in ’99 and ‘98	7

[7] See Appendix 2 for list of clone numbers, species and origin.



Species	n	Mean	s.e.	Pearson's	
correlation (r)	sig. (2-tailed)				
B. pendula	8	Height	17.75	1.82	-0.874** 0.004
		Survival	73.0	7.08	
B. pubescens	28	Height	14.08	0.74	-0.416* 0.028
		Survival	57.96	4.57	

** correlation is significant at the 0.01 level (2-tailed)
* correlation is significant at the 0.05 level (2-tailed)
data tested for normality prior to analysis, random sampling assumed.

Figure 5: The relationship between tree height and graft survival. The less shade tolerant species, *B. pendula*, shows a stronger linear negative correlation between these factors.

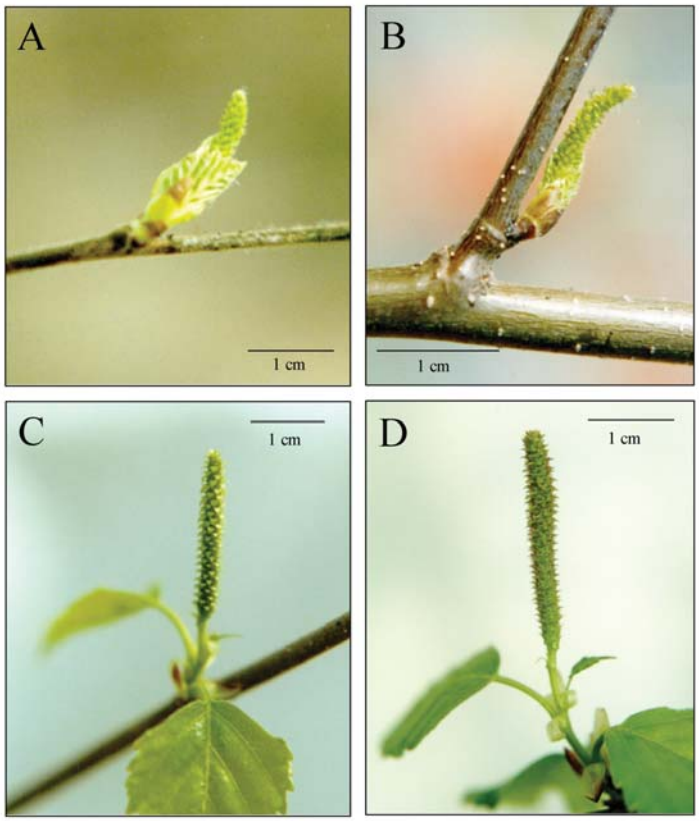


Figure 6: Stages of female catkin development in *Betula pubescens*. (A) Initial stage of catkin development in which the young bracts are visible. This inflorescence is developing concurrently with leaf flush. (B) The immature catkin elongates from within the bud and bracts are more clearly separated than in previous stage. This inflorescence is preceding leaf flush. (C) The catkin is fully elongated, standing proud of the leaves. Bracts are easily identified. (D) Ripe catkin ready for pollination. The stigma/styles are visible to the eye as red filaments protruding from between the bracts.

Timing of Bud Break, Female Flower Production and Pollen Release

Flowering patterns of *Betula* were studied in the cold-greenhouse seed orchard. The aim was to determine whether predictions could be made on the timing of phenological events. This would enable better planning of activities at pollination time in this seed orchard. Observations will have to be repeated over several seasons to see if patterns are consistent. No environmental controls were used and so results are expected to vary each year as birch phenology is sensitive to temperature sum (Heikinheimo and Lappalainen 1997), photoperiod (Håbjørg 1972) and chilling temperature (Myking and Heide 1995). This section discusses the observations made in Spring 2000.

Timing of bud break, female flower production and pollen release was recorded for all ramets[8] of 33 grafted clones growing in an unlit, unheated greenhouse. These plants were beginning their second or third year's growth since grafting. Plants were distributed about the greenhouse in incomplete, randomised blocks to minimise microclimatic effects. The calendar week in which an event occurred was noted. Dates used are tabled below.

week	date	week	date
10	6 – 12 March	11	13 - 19 March
12	20 - 26 March	13	27 March – 2 April
14	3 – 9 April	15	10 - 16 April

Average and modal timing of events was estimated for each clone and a series of inferences was drawn from the results. Initially, all clones were analysed together to give a general overview. Following this, *B. pendula* and *B. pubescens* clones were examined separately to see whether there were differences between the two species in the timing of physiological events. Only 128 *B. pendula* plants were recorded, as most grafts of this species had been moved to a plastic multi-span house.

It should be noted that this study only involves material grown in an unheated greenhouse. The timing of these observations were in advance of trees growing outdoors but lagged behind the trees growing in the multi-span plastic unit which had a more favourable growing climate than the greenhouse during early Spring.

Timing of events was recorded on a weekly, rather than daily, basis due to the number of observations to be made (382 trees in total). It should be noted that the difference between adjacent weeks represents a minimum of five days and a maximum of six days as recording was only carried out on Tuesdays, Wednesdays and Thursdays. Observations were made on a 'presence' or 'absence' basis, not on stages of development.

Results

Generally, the occurrence of an event was synchronised to within 10 days among ramets of a given clone. A small number of clones showed a greater spread in the timing of an event. For example, several ramets of clone #11 initiated leaf flushing in weeks 11 to 12 but the majority did not flush until weeks 13 to 14.

Timing of events may change from year to year depending on climate. It should be noted that these are the results of only one year and should not be used where accurate forecasting is required. A summary of observed events is given in Table 11 but the more complex, underlying trends are outlined below in point form and in Table 12:

⏩ *Vegetative bud burst:*

- In general, leaf flushing occurred in weeks 11 to 13.
- The earliest observed leaf flushing occurred in week 10 in clones #34, 50 and 19. All of these clones are *B. pubescens*.
- The latest observations of leaf flushing generally occurred in week 13. Clones #6, 16,

[8] A ramet is a vegetatively reproduced copy of a plant. Each ramet will have almost precisely the same genotype as the original parent tree.

Table 11: General summary of timing of leaf flush, female flower production and pollen release in *Betula* grafts grown in an unheated greenhouse. Degree of shading indicates approximate proportion of clones active during a given period.

	Week							
Event	9	10	11	12	13	14	15	16
Vegetative bud burst								
Female flower production								
Pollen release								

Table 12: Average number of weeks between leaf flush, female flower production and pollen release from male catkins in 26 grafted clones of *Betula* maintained in an unheated greenhouse (Spring 2000). Blank cells indicate an absence of male and/or female flowers.

Species	Clone	Weeks between leaf flush and female flower production	Weeks between leaf flush and pollen release	Weeks between female flower production and pollen release
pubescens	5	-0.7	0.8	1.5
pubescens	6	.	1.9	.
pubescens	8	0.0	2.2	2.2
pubescens	10	-0.8	2.0	2.8
pendula	11	-1.9	1.1	2.9
pendula	12	.	2.0	.
pendula	14	-0.4	2.6	3.0
pendula	16	.	1.5	.
pubescens	19	-0.6	1.0	1.6
pubescens	20	.	1.5	.
pubescens	21	0.0	1.2	1.2
pubescens	22	0.0	2.0	2.0
pubescens	23	0.0	1.2	1.2
pubescens	24	0.0	3.3	3.3
pendula	26	-1.5	1.0	2.5
pubescens	28	-0.8	1.9	2.8
pubescens	33	-0.9	1.3	2.2
pubescens	34	-0.1	.	.
pubescens	35	0.0	.	.
pubescens	37	-0.3	1.0	1.4
pubescens	38	-0.6	2.4	3.0
pubescens	41	-0.9	2.0	2.9
pubescens	42	-1.1	.	.
pendula	43	0.8	2.8	2.0
pubescens	44	0.4	.	.
pubescens	50	0.1	2.4	2.3

17 and 26 are the last clones to flush (the latter three clones are *B. pendula*).

- The last observation of leaf flushing occurred in week 14. This *B. pendula* clone (#11) showed a three week difference between ramets in the timing of this event.

⁃ *Female flower production:*

- Not all clones produced female flowers (although some of the clones which failed to flower during this greenhouse study did flower among the outdoor and multi-span material. Timing of events was not recorded for these grafts). Twenty-two clones flowered in this study but not all ramets of an ortet[9] flowered.
- In general, female flower production occurred in weeks 11 to 12 (see Figure 6).
- Earliest female flower production occurred in week 10 (clones #50 and 34).
- Latest female flower production occurred in week 13 (clones #37 and 43).
- Female flower production generally occurs within one week of leaf flushing on individual trees. Several clones produced female flowers prior to leaf flushing (clones #10, 11, 26, 33, 38

[9] An ortet is the original plant from which a clone is started through rooted cuttings, grafting or tissue culture, or other means of vegetative propagation. The original plus tree used to start a grafted clone for inclusion in a seed orchard is the ortet.

and 41) (Figure 6B). Only clone #26 consistently flowered as early as two weeks prior to leaf flush. Commonly, female flowering was concurrent with leaf flushing (clones #21, 22, 23 and 24) (Figure 6A). Only a small number of individuals flowered after leaf flush (clones #44 and 50).

⏩ *Pollen release:*

- Most clones released pollen in weeks 13 to 14 (see Figure 7).
- Earliest initiation of pollen release occurs in week 12 (clones #5, 19, 21 and 50) (Figure 7D).
- Latest initiation of pollen release occurs in week 15 (clones #6 and 41).
- Pollen release occurs one to three weeks after leaf flushing, but most commonly after two weeks. Clone #24 had the longest delay (three to four weeks) between leaf flushing and pollen release.
- Within individual trees, pollen shed occurred one to four weeks after female flower production but never before female flower production. The same pattern is reflected in the averages for each clone (Table 12).
- Most pollen is released from a catkin within one week of beginning pollen shed.

Nine of the 33 clones studied were *B. pendula*. Of these, only four produced female catkins and this only involved two, one, two and one ramets per clone where n = 17, 11, 4, and 16, respectively. Only six *B. pendula* clones bore male catkins. This involved 6% to 88% ramets per clone (n = 16). Of the 24 *B. pubescens* clones, only seventeen produced female catkins. The number of ramets per clone producing catkins was highly variable, ranging from 3% (n=35)

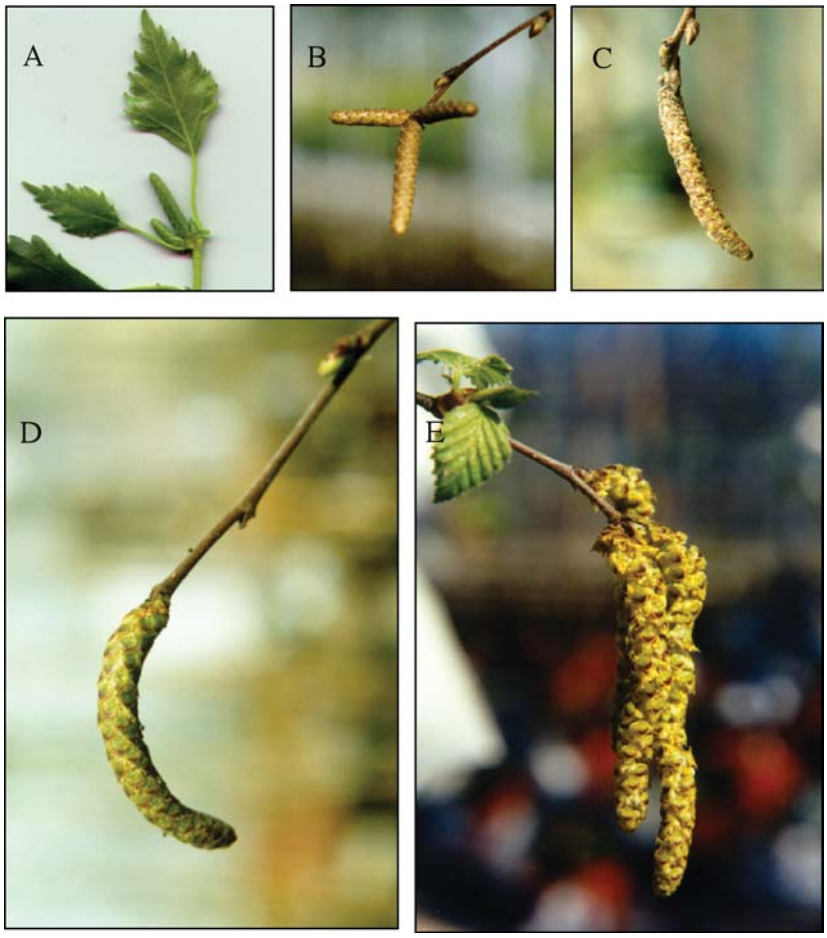


Figure 7: Stages of male catkin development in *Betula pubescens*. (A) A pair of young, green male catkins which appear in June-July. (B) Catkins grow through the summer to about 2cm, turning brown and eventually becoming dormant by autumn. (C) The following spring, before leaf flush, the male catkins become active and begin to elongate. (D) Elongation continues and bracts become green. (E) Bracts become yellow-green as elongation continues until bracts separate to reveal the male flowers within the catkin. Pollen is released in March-April.

to 90% (n=21). Three clones produced female flowers on all ramets but the sample sizes were small (n=4). Sixteen *B. pubescens* clones bore male flowers.

Conclusions

The aim of this particular study was to identify trends in *Betula* reproduction which could be exploited [or which could be limiting factors] in a breeding programme. It was shown that a number of clones in the current collection produce ripe female flowers early in the season and a number which release pollen late in the season. These clones are, therefore, not temporally available for inter-crossing. For example, in 1999 it would not have been possible to cross clones #34 or 50 with clones #6, 41 or 24. This lack of reproductive synchrony among clones could lead to the creation of temporally-isolated breeding subpopulations within a panmictic seed orchard. This has several repercussions such as altered mating patterns (reduced panmixis, increased inbreeding), increased chance of exposure to pollen contamination and imbalance in the contribution of clones to the seed orchard (El Kassaby 2000). For single pollen donor controlled crosses, as described here, one solution is to store pollen for early use the following year. It will be interesting to see whether these patterns, both general and within individual trees, are repeated in subsequent years.

It was not possible to demonstrate differences between the two species from the data available, although there are indications that *B. pendula* may flush later than *B. pubescens* under these conditions. One factor to bear in mind with this study is that the trees from which the scions for these grafts were made were of varying age and sampled from different areas of the canopy. This would be expected to have an effect on the flowering pattern of the grafts, at least at this early stage in their growth. Another factor to note is that the trees sampled to provide scions for these grafts are drawn from a large geographic spread and may have different temporal rhythms in leaf and inflorescence development to suit their local environment. Therefore, the comparison of clones from a widespread distribution under one set of conditions may mask or exaggerate the trends in which we are interested.

Despite the aforementioned drawbacks to this study, it should be noted that this information is important in the management of this seed orchard. Knowledge of the timing of flowering of this particular set of clones is vital for planning controlled pollinations. These observations should be recorded over a period of several seasons before any conclusions can be drawn.

Indoor facilities reduce pollen contamination from wild sources by physically isolating the orchard and by enabling female flower development and pollination to occur ahead of local outdoor trees. Phenological studies will be possible in the future using the multi-span plastic tunnel unit which has continuous environmental monitoring. This will enable a more intensive study of the timing, and possible prediction of phenological events. For example, Hallsdottir (1999) has shown that the accumulated thermal sum above 7.5ºC in Iceland correlates significantly with the *B. pubescens* pollen sum of the following flowering year. Such observations will provide information on how to manipulate the environment to optimise flower and seed production in the indoor seed orchard.

Study of Betula *Catkin Development*

A basic study of *Betula* catkin development was carried out and is presented in a series of photographs. These illustrate different stages of male and female catkin development which can be easily observed by eye. No differences were noted between *B. pubescens* and *B. pendula* inflorescence development at this level of observation.

This information is a basic requirement for carrying out controlled pollinations in native Irish *Betula*. It also presents the problems which make the anticipation of seed production difficult. For example, it is commonly acknowledged that female catkins are produced from 'short shoots', i.e. buds which are carried on a short basal stem (Maillette 1982). This has been our experience but, additionally, many of the female inflorescences which we observed had developed from buds which were not borne on short shoots (Figure 6A and B). This makes it more difficult to anticipate female catkin production. This situation is exacerbated by the fact that at least 30% of the female catkins observed during this study appeared before or at the same time as leaf flush. This means that a tree which appears to be dormant could commence flowering within the next 24 to 48 hours. As a result, it is vital to monitor the grafts daily to identify and, where necessary, to protect new inflorescences from pollen contamination.

Betula is monoecious, with male and female flowers being carried separately on the same plant. The female inflorescences (catkins) are erect aggregations of 2 to 3-flowered cymes, each with a subtending bract and varying numbers of bractlets. Each female flower has a single compound 2-carpelled pistil with two deeply divided styles and an inferior ovary. A placental septum divides the lower part of the ovary into two locules, each containing two ovules. Figure 6 shows the development of female catkins of *B. pubescens* which occurs during April-May. Figure 6A shows a two to three day old female catkin. The bracts are lying close together. In this instance, development is concurrent with leaf flush. After three to four days the catkin elongates to ~1.5 cm and the scale-like bracts begin to separate and become more apparent (Figure 6B). In this example, flowering precedes leaf flush. After six to eight days the inflorescence is fully elongated and stands erect on the shoot (Figure 6C). Bracts are curled back. Pale yellow-green filamentous styles may be visible between the bracts. After eight to ten days the stigma are receptive to pollen and the stigma-style filaments appear red in colour. Dahl and Fredrikson (1996) observed that stigmatic tissues of *B. pendula* remain viable during pollen tube growth, thereby providing the opportunity for pollen interaction. They found that when an ovule is penetrated by the first pollen tube it begins to outgrow the other ovule. This observation is supported by Pasonen *et al*. (1999) who found a positive correlation between pollen tube growth rate and seed-siring success in a series of *B. pendula* clones. Dahl and Fredrikson (1996) observed that, even if the other ovule is also penetrated, its vascular support soon shrivels and the megagametophyte withers. Successful fertilization of both ovules was never seen in their study. Williams *et al*. (1999) studied the paternity of pollen tubes growing in female tissues of *Betula papyrifera* (2n = 28) and *B. occidentalis* (2n = 84) following intra-specific and inter-specific crosses. They concluded that biases in seed-siring were due to male x female post-pollination interactions such as pollen tube incompatibility, slower pollen tube growth, and delayed mitosis in the generative cell. In mixed-species pollinations, male x female barriers resulted in almost complete conspecific siring bias. They found no evidence for male x male competition. This is supported by evidence from Pasonen and Käpylä (1998) who found only positive interactions between pollen grains *in vitro*. Following pollination the bracts of the female inflorescence close and the catkin gradually becomes pendulous. Seed development results in a fruit which is a 1-seeded samara.

Figure 7 shows the maturation process in *Betula* male catkins. The male inflorescences are pendulous

catkins composed of clusters of 1 to 3 simplified flowers each with a subtending bract and 2 to 4 stamens. Unlike female catkins, it is possible to anticipate pollen production because male catkins appear about ten months before they ripen. Small green catkins develop in June-July, usually at the branch ends (Figure 7A) but can also occur along branches at leaf axils. Male catkins can occur singly, in pairs or as triplets. They elongate during the summer, eventually becoming dormant as the growing season ceases. At this stage they are approximately 2 cm long and have become brown in colour (Figure 7B). Krizo and Slobodnik (1997) examined *B. pendula* pollen both in over-wintering catkins and immediately before pollen shed. They found that, shortly after meiosis in early autumn, tetrad cell disintegration occurs and, just before winter dormancy, pollen grains develop their definitive shape and external appearance, but seem to contain only one nucleus. The following spring, before leaf flush, the male catkins become active and begin to elongate again (Figure 7C). The tapetum atrophies, leading to the formation of bi-nucleate pollen grains which subsequently enlarge inside the anther to their final size. Externally, the bracts become greener and begin to separate as the structure elongates and starts to become pendulous (Figure 7D). Some catkins extend to 7 to 8 cm. Gradually the bracts become yellow and the ripening anthers begin to protrude from between them. Pollen release commences at this stage (Figure 7E). Pollen release is anemophilous and tends to be acropetal with most pollen being shed within one week. April-May is the main pollen release period outdoors but in the indoor orchard most pollen is shed in late March to mid April.

It is possible to obtain viable pollen from select trees by collecting branches with dormant male catkins in January-February and ripening them. This is done by cutting the base of the stems beneath water in order to prevent embolisms. The stems are then left to stand in a jar of water in a bright, airy part of the greenhouse where the catkins mature normally. With material taken from the ‘wild’ it is important to check for the presence of caterpillars inside the catkins. Infested catkins must be removed with a sharp blade to prevent the larvae from spreading to healthy catkins. Up to 50% of catkins may carry larvae.

Production of Seed from Controlled Crosses

Controlled pollinations were carried out between grafted plants. Ripening female catkins were covered with brown, windowed envelopes to isolate them from stray pollen. Pollen was collected from several sources: (i) twigs from phenotypically superior mature trees bearing male catkins were harvested in Spring and flushed by standing them in water in a well-lit area; (ii) waxed male catkins from current season's grafts; and (iii) male catkins on previous season's grafted trees. More than half the male catkins from sources (i) and (ii) above were lost due to caterpillar damage. No such infestations were encountered with source (iii) where catkins developed in the protected environment of the indoor seed orchard.

A series of controlled pollinations was carried out in spring 1999 and 2000 among the grafts from selected *Betula*. In 1999, disconnected, partial diallele crosses were carried out in which one pollen donor was crossed with a female recipient. In 2000, a new approach was taken in which most controlled pollinations were polymix crosses, i.e. pollen from several genotypes was mixed and then used to carry out pollinations.

The ideal situation would be to carry out a full set of connected diallele crosses, i.e. a series of crosses in which each genotype is crossed with every other genotype within a group of five to six individuals, with each group overlapping by one or two individuals (to cross each genotype in the collection with every other genotype would involve over twice the number of crosses). This would enable a thorough study of heritability of characteristics to be carried out. Unfortunately, not all genotypes produced both male and female catkins so only disconnected, partial diallele crosses were possible in 1999. The resultant seed has been germinated and grown on for inclusion in field trials. The main objective of producing these full-sib and half-sib plants was to provide material with a known range of 'relatedness' to assist in estimating genetic parameters and environmental effects. By only using open pollinated material in our field tests, our ability to estimate heritabilities of characteristics would be constrained.

It was decided that the polymix method is useful for mass seed production until it has been determined which of the parent trees are genetically superior. Each available genotype was crossed with 5 to 20

Table 13: Pollen mixtures used in *B. pendula* polymix crosses. 'X' indicates the presence of pollen from the relevant clone in the pollen mix.

	Clone no.										
polymix no.	**3**	**4**	**11**	**12**	**14**	**16**	**17**	**26**	**27**	**43**	**45**
Pm1			x	x		x	x	x			
Pm4		x	x	x	x	x	x				

Table 14: Pollen mixtures used in *B. pubescens* polymix crosses. 'X' indicates the presence of pollen from the relevant clone in the pollen mix.

	Clone no.																				
Polymix no.	**1**	**2**	**5**	**6**	**8**	**9**	**10**	**13**	**15**	**19**	**20**	**21**	**22**	**23**	**24**	**28**	**30**	**32**	**33**	**37**	**41**	**50**
pm2	X		x		x		x			x		X				x						
pm3											x		x	x	x			x		x		x
pm5	X		x	x	x		x		x	x	x	x	x	x	x	x	x	x		x		x
pm6	X		x		x		x			x	x	x	x	x	x	x		x				
pm9	X	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	
pm10	X	x	x	x	x	x	x		x		x	x		x	x			x	x	x		
pm11	X	x	x		x		x				x	x		x		x		x				

mixed genotypes (Tables 13 and 14). This is a practical approach as each seedlot from a mother tree will carry a broad range of full-sib and half-sib genotypes and avoids 'placing all ones' eggs in one basket' when the genetic merit of the male is unknown. One issue to bear in mind is that each male contribution to a polymix cross may not be equally represented in a seedlot due either to uneven proportions of pollen being applied to the female catkin or to female compatibility biases, although pollen competition appears not to be a strong factor (Williams *et al*. 1999).

Pollen from ripe male catkins was applied to ripe stigmas using a fine squirrel-hair paintbrush. Female catkins were re-covered after pollination until seed-set. Surplus pollen was stored at 1ºC for a maximum of 10 days.

Due to lack of availability of pollen and female flowers from each genotype it was not possible to carry out a full set of diallele crosses. Shortage of female flowers was the main limiting factor. Few interspecies crosses were performed in 1999 as the nine interspecies crosses in 1998 had failed to yield viable seed. Selfing was avoided in 1999 as two selfed crosses carried out in 1998 had failed to produce seed. Pollen from trees of lower quality was not commonly used. Individuals from the same site were not generally crossed. One reason for this was to avoid mating close relatives from small populations as this can lead to the expression of deleterious recessive alleles, i.e inbreeding depression. A converse aim was to provide opportunities for outbreeding enhancement, also referred to as heterosis. Different populations of a species can possess different recessive deleterious alleles. Offspring between parents from two such separate populations may not be homozygous for the same deleterious alleles. The offspring may, therefore, be fitter than either parent because the effects of the deleterious alleles have been masked. However, it should be noted that this strategy can also lead to a situation in which the off-spring are less fit than the parents. Isolated populations can evolve complexes of genes that interact well within that population, but poorly when the genes are mixed through inter-population matings (Montalvo and Ellstrand 2001). This is called outbreeding depression.

Results

Seventy-eight percent of pollinated female catkins survived on first year grafts. Eighty-eight percent survived on second year grafts. The cause(s) of female catkin loss were not determined. All intra-specific crosses in 1998 produced viable seed while none of the inter-specific seed germinated. In 1999, a total of 72 combinations of controlled crosses were carried out. Of these, 57 were *B. pubescens* intra-specific, eight were *B. pendula* intra-specific and seven were inter-specific. Seed was obtained from forty-six, three and six of these combinations respectively. Viability and germination rates of 1999 seed were not estimated. Seed produced in 1998 and 1999 was sown in Spring 2000 for field testing.

Germination of Freshly Harvested Seed

The polymix crosses were carried out in Spring 2000 and the mature seed was collected from late June onwards. A test was carried out to see whether it would be possible to germinate this seed and grow the plants to a height suitable for the spring 2001 planting season.

Method

Many of the grafted trees in the multi-span unit set seed ahead of normal time. Ripe seed was collected in the last week of June from six *B. pendula* trees. These had been pollinated using poly-mixed pollen. The seed was kept overnight in brown envelopes to dry slightly. They were then wrapped in pieces of nylon stocking and kept in running water for four days. This was to see whether germination-inhibiting substances could be washed out, thereby allowing summer germination. Additional seed from one of the seedlots (4 x PM1) was sown without prior treatment. This was not a proper control as this seed was left drying in ambient conditions during the four day period.

The seeds were surface sown on seed trays containing 2.5 cm depth of the standard nursery medium. They were watered with Cheshunt's compound to prevent damping off and placed in the multi-span unit.

Results

Germination commenced within four days and within ten days seedlings were approximately 1 cm tall with 1 to 2 true leaves. These plantlets were pricked out and grown on in the multi-span unit but they did not achieve the required minimum 25 cm planting height for spring 2001.

Germination rate was estimated for three summer harvest seedlots. Normally the maximum germination expected for *B. pubescens* and *B. pendula* is reported at 40%. As shown in Table 15, the germination rates of 68 and 75% for the two *B. pendula* seedlots was far in excess of this figure. The unsoaked seedlot had not commenced germination after 19 days, although sporadic germination in September yielded a final 21% germination rate. The *B. pubescens* germination rate was lower (36%), although this would normally be considered to be a reasonable yield.

Several factors may contribute to these high germination rates:

- favourable seed production conditions in the multi-span indoor seed orchard;
- freshness of the seed sown at harvest;
- pre-germination treatment;
- favourable germination conditions (temperature, humidity and daylength).

Germination rates need to be estimated for several more seedlots to see whether these high rates are reproducible. Such experiments are of value as an increase in germination level means that less seed needs to be produced. This has economic implications in situations where seed is produced in indoor seed orchards.

Table 15: Germination rate of two *B. pendula* and one *B. pubescens* polycross seedlots 19 days after sowing.

Species	Female code	Pollen lot code	Sowing date	Number of seeds sown	% germination
B. pendula	4	PM1	27/07/00	200	68.0
*B. pendula**	4	PM1	27/07/00	200	21.0
B. pendula	43	PM4	27/07/00	200	74.5
B. pubescens	15	PM9	21/07/00	300	35.7

*dried with no pre-soak, germination after 3 months.

Seedling Production

Timing of sowing

Autumn and spring sowings were examined to obtain information on the optimal timing and conditions for sowing birch. Standard peat mix with a light casing of white granitic sand was used for sowing. Seed stratification involved storing seed for three weeks at 0ºC in a damp sand : peat mix (3:1). Experiments to evaluate different stratification media were also carried out. Four sets of germination experiments are briefly described below.

Expt. 1: Unstratified seed was sown in September with a 16 hour daylength at 16ºC. The resulting plants were retained under these conditions until April when they were moved to an ambient greenhouse.

Expt. 2: Unstratified seed was sown in September with a 16 hour daylength at ambient temperature. The resulting plants were moved to an ambient greenhouse in late November to induce dormancy.

Expt. 3: Pre-chilled, unstratified seed was sown in March under ambient greenhouse conditions. These plants were retained in an ambient greenhouse.

Expt. 4: Stratified seed was sown in January 2000 under ambient greenhouse conditions. The plants were retained in an ambient greenhouse.

Results

Notes: Cheshunt's Compound proved vital for the prevention of damping off of seedlings. There was a large variation in the heights of seedlings even within single parent progeny. The 1999 growing season was relatively sunny and warm so the greenhouse conditions in which these studies were carried out may have resulted in slightly higher than average growth rates.

Expt. 1: Germination occurred after two weeks. By April the plants (*B. pubescens* seedlot 'Ardee') had reached a mean height of 41.7 cm (s.e. 3.0) (n=40, 750 ml containers) and by the following November had attained a mean height of 63.9 cm (s.e. 2.8).

Expt. 2: Germination occurred after 3 to 4 weeks. Dormancy of the 6 to 9 cm seedlings occurred in November, followed by normal flushing in March. By the following November, three seedlots of *B. pubescens* grown in 100 ml containers achieved the heights given in Table 16. The growth of Ardee was significantly greater than that of either Portarlington seedlot. The performance of 'Ardee', in 750 ml containers (n= 25; mean 70.8 cm; s.e. 2.5) was significantly greater than its growth in 100 ml containers. This infers that greater heights could have been achieved with larger containers.

Expt. 3: Low rates of germination occurred after 4 to 6 weeks with a second flush of germination four months later. All plants in this experiment were grown in 750 ml containers, n = 12. By November, plants from seedlot 'Portarlington1' and three controlled crosses of *B. pubescens* reached the heights shown in Table 17. These heights are in the optimal range for planting stock.

Table 16: Growth of three seedlots of *B. pubescens* in 100 ml containers following September sowing at ambient temperature with supplemental light (16 hour day).

Seedlot	n	Height (cm)	s.e.	Subset for alpha = .05*	
Portarlington1	55	33.20	2.68	a	
Portarlington2	151	37.44	1.70	a	
Ardee	135	48.19	1.78		b
Sig.				0.342	1.000

* Group sizes are unequal; Harmonic Mean Sample Size = 93.26

Expt. 4: This study showed that it is possible to germinate *B. pubescens* and *B. pendula* seed successfully in January-February. Germination occurred after 6 to 8 weeks and the seedlings grew slowly initially but increased growth as daylength and temperatures increased. By March the plants were approximately 4 cm tall. This sowing protocol was used for future plant production.

Discussion

By growing plants under supplemental heat and light (Expt. 1) it is possible to produce tall plants within one year of sowing (>60 cm) but this has several drawbacks. Such facilities are expensive for large-scale operations. Maintaining plants in a growing condition through the winter also increases labour input and the risk of pests and disease. The plants produced were not hardy enough to plant out in spring and by the following planting season they were taller than the optimal planting stock size (30 to 60 cm).

Autumn sowing without supplemental heat and with a dormant period (Expt. 2) appears to produce plants of similar size to trees grown and over-wintered with supplemental heat and light. The container sizes used were different so comparisons are difficult to make although, in one seedlot where containers were the same size, the plants which experienced dormancy were taller (Ardee, 70.8 cm; s.e. 2.5) than the treatment which did not experience dormancy (63.9 cm; s.e. 2.8). This difference between treatments was not significant, as indicated by a Mann Whitney non-parametric test for independent samples (2-tailed asymp. sig. = 0.147). This raises the question of whether maintaining plants in growth phase through the normal dormant season adversely affects their subsequent growth.

Spring-sown plants grew rapidly enough to achieve a suitable planting stock size in one growing season (Expt. 1). This was achieved without recourse to supplemental heating or lighting and reduced the amount of time in the nursery by several months. Expt. 4 showed that spring sowing can be carried out in January. This should allow optimal planting stock size to be achieved comfortably even if the growing season is not as warm and sunny as 1999. Repeating the experiment in a plastic poly-tunnel in 2000 resulted in plants growing too vigorously. Under plastic, March is early enough to achieve optimal planting height for the following spring. It may even be necessary to move the plants outdoors to slow their growth and to harden them off.

It was interesting to note that despite the close spacing (4 cm) of the seedlings grown in Hilleshog trays, some seedlots appeared to show branching characteristics in the first year. Disproportionately large branches (dlbs) with a diameter exceeding 30% of the stem diameter occurred on 8% and 7% respectively of 'Ardee' and 'Portarlington2' progeny. This figure increased to 20% for Portarlington1. At this early stage these observations may not be of significance although it will be interesting to follow this trait in different families. The formation of disproportionately large branches is a major cause of poor form in Irish birch. It is not known whether this trait has a genetic component. If it does then the selection of superior individuals which show no development of disproportionately large branches, for inclusion in a quality improvement programme, may help reduce the incidence of this defect. If this is predominantly an inherited trait, early identification would be a valuable tool. Recent research, using AFLP markers, suggests that branch frequency is genetically linked in *B. pendula* (Welander *et al*. 2000).

Table 17:Growth of four seedlots of *B. pubescens* in 750 ml containers following stratification and ambient March sowing in a cold greenhouse.

Seedlot	n	Height (cm)	s.e.	Subset for alpha = .05*
Portarlington1	12	50.75	3.16	a
13x18	12	61.25	2.07	a
13x28	12	51.42	2.59	a
15x23	12	51.17	2.27	b
Sig.				

* Group sizes are unequal; Harmonic Mean Sample Size = 93.26

Production of Planting Material for Field Trials

Method

Stratification: Seed was mixed through damp sand:peat (3:1) and stratified by storing in plastic bags for 4 to 5 weeks at 0ºC.

Sapling production containers: Rootrainers were assembled and filled with substrate. There are 40 cells per tray. Each cell measures 4 x 4 cm and is 17 cm in depth. Vertical flanges encourage downward growth of roots, thus preventing plants becoming pot bound. Twelve cubic metres of peat-based substrate were required to fill 38,000 Rootrainers.

Sapling production substrate:

Coarse nursery grade peat
Osmocote @ 4.6 g l^{-1}
Ground Lime @ 1.0 g l^{-1}
Dolmitic Lime @ 2.3 g l^{-1}
suSCon Green‘ @ 1.0 g l^{-1}

Sowing: Sowing was carried out between 22 February and 7 March. Direct sowing was carried out by placing small quantities of seed/sand:peat mix on the surface of the growing medium in Rootrainers. Between 3 and 10 seeds were sown per cell based on: (a) amount of seed available and (b) a maximum expected seed viability of 40%. Up to 20 seeds per cell were sown for seedlots obtained from Scottish and German sources which had been in storage for five years as birch seed viability has been reported to decline swiftly over time (Granstrom and Fries 1985). Excess seed was spread over the surface of peat-based substrate in seed trays. Four hundred seed trays were thus sown with variable amounts of seed. All seeds were sprayed immediately after sowing with Cheshunt's compound (~30 g/10 litres) to prevent damping off. Further applications were made five and 10 days after sowing. No damping off was observed in any treatment.

Plant material: Ninety-eight *B. pubescens* and 32 *B. pendula* families of Irish origin and one *B. pendula* family of French origin were sown. Seventy-six families from non-contiguous, partial dialleles were also sown. This included 65 *B. pubescens*, six *B. pendula* and five inter-specific families. Seedlots were sown according to family. Families were kept separate within provenances to ensure that all families within a provenance would be equally represented. Five German, and seven Scottish provenances of *B. pendula* in which seed from a number of families had been mixed were also sown.

Nursery conditions: The Rootrainer-sown seedlots were maintained in a double-skinned, ventilated, plastic multi-span unit. Automated temperature control prevented the temperature exceeding 27ºC. An overhead watering system was installed in the multi-span house to allow automated watering. Watering occurred twice a day for 20 minutes at 06.00 h and 18.00 h.

Seed trays were maintained in an unheated greenhouse. Overhead watering was applied as required.

Results

Germination: Germination generally began 7 to 10 days after sowing. Irish seed from both *B. pendula* and *B. pubescens*, which was collected the previous autumn and cold-stored over winter, demonstrated uniform germination rates within families. Foreign seed lots which had been held in cold storage for several years showed staggered germination with as much as four weeks between early and late germinating individuals. This may have been due to several factors including:

a) These seedlots contained mixtures of families which may have different germination timing. The fact that this material was only stratified for three weeks may not have allowed sufficient time to cause complete dormancy breakage for all families.

b) Long-term storage may affect germination rates of different families or individual seeds to a greater or lesser extent.

It was not feasible to carry out germination rate

estimations for each seedlot. Sowing families separately within provenances proved the correct choice as 10% of seedlots either failed to germinate or germinated at such low levels that they failed to provide sufficient planting stock for the provenance trials. If seed had been mixed prior to sowing, families would have been disproportionately represented or, in some cases, entirely absent without this fact being registered.

Thinning: Thinning out of excess seedlings began on 4 April and continued until 9 May. Once seedlings were 2 to 4 cm in height they were thinned. Empty cells were filled using the spare, thinned-out seedlings or seedlings from the seed trays.

Growth of seedlings: In the first week of May seedlings in the multi-span unit were 3 to 6 cm high. Six weeks later seedlings were in the 20 to 80 cm height range, the majority exceeding 40 cm. It would have been preferable to move the plants outdoors at 30 cm height to slow down their height growth and to harden them off. Seedling heights of 14 *B. pubescens* seedlots were measured in late June, just four months after sowing (Figure 8). These seedlots are all derived from specific crosses. Seedlots are referred to by the convention 'mother tree' x 'pollen source', e.g. 2x6 indicates that the seeds were produced from mother tree number 2 following pollination by tree number 6. Therefore, seedlots 15x1, 15x13 and 15x19 derive from the same maternal source but have different paternities. Thirty-seven full-sib seedlots were planted in the field trials (see Appendix 3 for details).

The highest growth rate was achieved by seedlot 5x19 (69.0 cm, s.e. 2.58) although this was not significantly higher than the growth rates achieved by seedlots 15x1, 15x13, 15x19, 19x6, 19x13 (Table 18). All seedlots significantly outperformed seedlot 19x30. Tree #19 performed well in all crosses, whether used as maternal or paternal source with the exception of the 19x30 cross. It will be interesting to follow the performance of tree #30 in other crosses to examine whether: (a) It is generally a poor performer; (b) it only performs poorly in combination with #19; and (c) the slow initial growth continues into future growing seasons. Crosses involving tree #13 or #15 grew well. Poorest growth was recorded for crosses 19x30, 10x8 and 2x35. There was no significant difference in performance between these three seedlots. It will be interesting to follow the performance of these seedlots to see whether these early growth differences are maintained into the future.

As a result of their rapid growth, the trees were largely unlignified. They were moved outdoors in late June and an overhead watering system was installed. The plants were kept relatively dry in order to induce hardening off. Monitoring for drought was important as birch

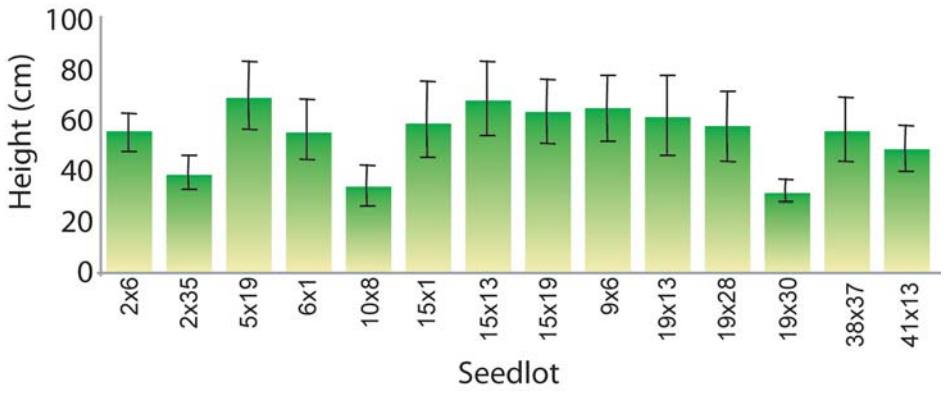


Figure 8: Seedling heights of 14 *B. pubescens* seedlots four months after sowing in the plastic multi-span unit (standard deviation shown).

does not tolerate drying out. Growth continued, but at a reduced pace, and the trees hardened off prior to dormancy. Heights at dormancy were generally in the range 35 to 105 cm and traits such as colour, branchiness, height and root-mass were already apparent between families. The trees were maintained outdoors at Teagasc Kinsealy until planting time. November to March was spent recording the height and diameter at 20 cm of each tree and labelling with a unique code so that each tree can be tracked in the future. This allows the trials to function as breeding seedling orchards, enabling backward selection of superior genotypes in the future.

Planting: Trees were removed from the rootrainers in late-February to early-March and were sorted into forestry bags. They were then transported to the sites and planted. Planting methods and site descriptions are given in Appendix 4.

Table 18: Analysis of seedling heights of 14 *B. pubescens* seedlots four months after sowing in the plastic multi-span unit (standard deviation shown).

Seedlot	n	Mean	s.e.	Subset for alpha = 0.05					
19x30	40	31.38	0.68	a					
10x8	47	33.43	1.19	a					
23x5	36	38.28	1.10	a					
41x13	40	48.03	1.48		b				
2x6	40	54.60	1.18		b	c			
6x1	37	55.24	1.95		b	c	d		
38x37	35	55.29	2.16		b	c	d		
19x28	40	57.03	2.21		b	c	d		
15x1	37	59.49	2.48			c	d	e	
19x13	37	61.16	2.64			c	d	e	f
15x19	36	62.64	2.12			c	d	e	f
19x6	40	64.15	2.07				d	e	f
15x13	36	67.92	2.47					e	f
5x19	26	69.04	2.58						f
Sig.				.390	.060	.160	.067	.110	.185

Tukey HSD using Harmonic Mean Size = 37.06

Production of Clonal Birch

Cuttings and micropropagation were two methods investigated for the production of clonal birch.

Cuttings

Cuttings from Spring 1998 grafts of two *B. pendula* and two *B. pubescens* clones were inserted in Autumn 1998 and early Summer 1999. A variety of cuttings were taken, including single node, two node, and full side-shoots (<12 cm). These were dipped for 60 seconds in Captan fungicide and Seradix rooting powder was applied to the base of the cuttings prior to insertion (n=308 ± 20 cuttings per clone). A substrate of 3:1 coarse sand : peat was used. Cuttings were maintained on a mist unit with basal heat (16 ± 2ºC) for 3 to 4 months.

Only one clone rooted (*B. pubescens* clone #6) and that was at a very low rate of 12% from early summer cuttings. It was determined that conventional cuttings were not an efficient method of clonal *Betula* production. The Scottish birch improvement programme also experienced difficulty in propagating these species (Blackburn and Brown 1988b).

Micropropagation – from nodal explants

A series of *Betula* clones were initiated into in vitro culture during different seasons and from different sources. Surface sterilisation routines and initiation and multiplication media were tested to determine a suitable protocol for the *in vitro* culture of *Betula*.

Contamination of newly initiated material from the 'wild' lead to losses of up to 80% of explants. A protocol was developed which reduced contamination losses to 25% without apparent additional damage to the plant tissues. Buds were agitated in the following series of solutions: five minutes in distilled water with three drops Tween 20/100 ml; 20 seconds in 90% ethanol; 8 minutes in 0.1% HgCl2; 12 minutes in 30% Parazone (x2); 10 minutes sterile distilled water (SDWx4). This became the standard sterilisation protocol for further experiments.

Surface sterilised buds were aseptically trimmed and placed on agar-solidified medium (Appendix 5) in a controlled temperature room at 25 ± 3ºC and a daylength of 16 hours. Following initiation, shoots were transferred to shoot multiplication media.

Results - Initiation

Dormant winter buds from selected trees were heavily contaminated and failed to grow in vitro with the exception of clone #4, a 101 year old *B. pendula* from Phoenix Park. Mid to late summer buds from 1 and 2 year old grafted trees had lower contamination rates (0 to 50%) but initiation survival rates were low. Clone #17, a *B. pendula* from Collin's Bog, Abbeyleix, was initiated into culture by this method. Two *in vitro* micropropagated clones derived from controlled crosses were successfully initiated into culture from 1 year old seedlings. These clones were both *B. pubescens.* One is a cross between a tree from Portarlington (#13) and one from Shelton Abbey (#28). The other is a cross between a mother tree from Abbyleix (#15) with pollen from an individual from Drumshanbo (#23).

QRC and C1005 media were the most successful initiation media. Shoots initiated on BET1, GERM1, GERM2 or M3 were often vitrified and more than 95% gradually turned brown and died. Cultures which survived *in vitro* took 3 to 6 months to stabilise, i.e. for steady growth to occur, for vitrification to cease and for shoot internode elongation to commence.

Results - Shoot production

Established cultures of clone #4 were grown for 4 months on GERM1, GERM2 or M3 shoot multiplication media alternated with QRC medium. Subculturing occurred every 25 days. Results were compared after 25 days on the three media (Figure 9). Shoots from the GERM1 treatment were the tallest and had slightly longer internodes than GERM2. Rooting occurred with all three treatments during the QRC phase. The M3 treatment produced shorter shoots of greater diameter and more roots per shoot

than the other treatments. Shoot multiplication rates on GERM1 and GERM2 treatments are x3/25d. For M3 the rate is x2/25d. Shoots on M3 demonstrated intervenal chlorosis and reddening of the stem. Shoots on GERM1 and GERM2 were healthy. Levene's Test was applied pairwise to check for equality of variances. Equal variances could not be assumed so a one-way ANOVA using Dunnett's T3 test was used to determine which means differed for each dependent variable. It was estimated that the means of all treatments were significantly different from each other (at the 0.05 level) for the three parameters observed. GERM1 became the standard shoot multiplication medium used, alternated with QRC.

Results - Rooting

A rooting medium, GERMR1, was tested on shoots from the M3⇔QRC cycle. Ten days after being moved from M3 to GERMR1, 100% rooting was achieved. After 20 days there were 3.5 ± 1.1 roots per shoot (n=20) with a mean root length of 5.3 ± 0.7 cm. Plantlets were weaned into Jiffy 7 peat plugs.

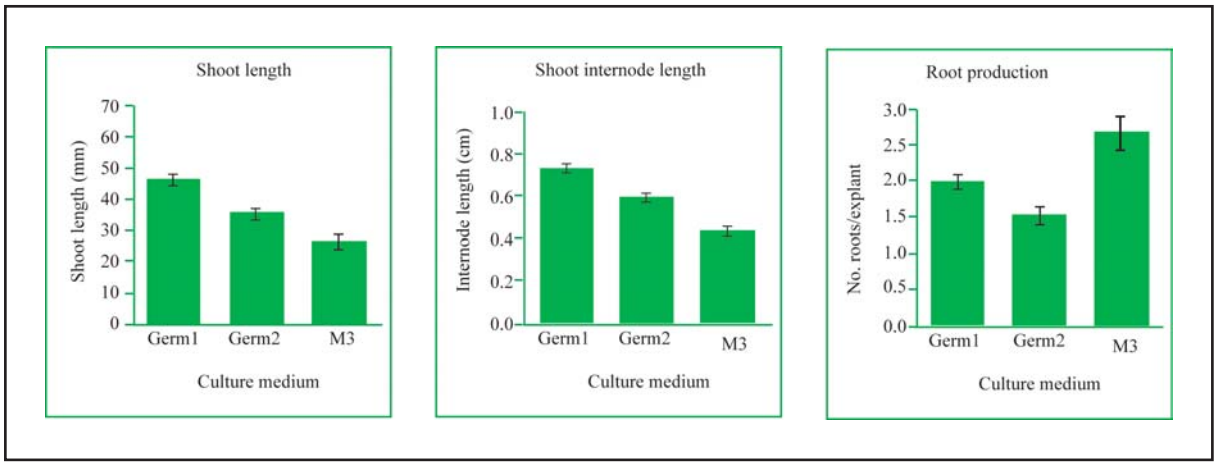
Clone #4 is routinely micropropagated using a GERM1⇔QRC medium cycle. Rooting on QRC in these conditions is 80 to 100% so the rooting medium GERMR1 is only used where 100% rooting is required.

Micropropagation – from seed

In vitro cultures were established directly from seed harvested from two different plus trees. As a result there are now two sets of half-sibling clones growing *in vitro*. Each set consists of twelve clonal lines. A sterilisation method was developed which gave low levels of contamination and no apparent tissue damage to the explants used to initiate the cultures.

Method

Seeds from one *B. pendula* tree and one *B. pubescens* tree which had been stored dry for four months at 0ºC were soaked in tap water for 48 hours. Excess water was decanted off and the seeds kept damp at 18ºC in ambient light conditions for two weeks. At this stage the seeds ranged from ungerminated to 2 cm seedlings. The seeds/seedlings were surface sterilised by hand-shaking them in distilled water with three drops of Tween 20 per 100 ml for 10 minutes. This was followed by shaking in 0.1% HgCl for seven minutes and four rinses in SDW. They were subsequently transferred entire to Petri-dishes of semi-solidified nutrient medium (M3) as defined in Appendix 5. Cultures were retained on M3 in a controlled temperature room at 25 ± 3ºC and a daylength of 16 hours.



Medium	n	Mean shoot length (mm)	s.e.	Mean internode length (cm)	s.e.	No. roots/explant	s.e.
Germ1	68	46.1	1.98	0.73	0.02	2.00	0.11
Germ2	76	35.3	1.92	0.59	0.02	1.53	0.12
M3	31	26.5	2.15	0.43	0.02	2.68	0.24

Figure 9: Mean and standard deviations for growth and root production of clone #4 (*B. pendula*) on three shoot production treatments (standard error shown).

Results

Seventy percent of seeds/seedlings were surface-sterile. Approximately 30% of seeds germinated in total, including contaminated seed. Contamination generally presented as the occurrence of white fungal hyphae. All contaminated material was discarded. Once seedlings were 2 to 3 cm high they were dissected into 2 to 3 nodal explants and roots were removed. Explants were transferred to GERM1 medium for four weeks and thereafter alternated between QRC medium and GERM1 medium (Appendix 5). GERM1 medium encourages shoot proliferation and QRC provides a 'resting medium' which is used alternately with GERM1 as it was noted that prolonged periods on growth regulator-containing media tended to cause vitrification and shoot distortion.

Rooting of shoot explants was achieved at levels of 90 to 100% for all clones within two weeks on GERM1 medium supplemented with 0.1 mg l^{-1} IBA. Five half-sibling clones from each family have been successfully weaned out into the greenhouse for inclusion in field trials.

In vitro cultures are being maintained for future studies.

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APPENDIX 1

TOTAL AFFORESTATION (HECTARES) BY STATE AND PRIVATE SECTOR IN THE REPUBLIC OF IRELAND (1980-1999)

Year	State	Private	Total	% private
1980	5922	268	6190	4
1981	6099	275	6374	4
1982	6,016	498	6,514	8
1983	5,698	327	6,025	5
1984	5,192	473	5,665	8
1985	4,625	617	5,242	12
1986	4,689	2,280	6,969	33
1987	5,395	2,954	8,349	35
1988	7,112	4,596	11,708	39
1989	6,629	8,498	15,127	56
1990	6,670	9,147	15,817	58
1991	7,855	11,292	19,147	59
1992	7,565	9,434	16,699	56
1993	6,827	9,171	15,998	57
1994	6,431	12,837	19,268	67
1995	6,117	17,343	23,460	74
1996	4,426	16,555	20,981	79
1997	3,094	10,581	13,675	77
1998	2,926	10,002	12,928	77
1999	890	11,776	12,666	93

Data Source: Forestry Yearbook (2001), Irish Timber Growers Association

APPENDIX 2

SPECIES, ORIGIN AND CLONE NUMBER OF INDIVIDUALS GRAFTED INTO THE INDOOR GENEBANK/SEED ORCHARD AT TEAGASC KINSEALY

Clone number	Location	Species (years)	Estimated age	Height (m)
1	Kilcock	*B. pubescens*	35	16.0
2	Kilcock	*B. pubescens*	15	-
3	Phoenix Pk.	*B. pendula*	100	26.0
4	Phoenix Pk.	*B. pendula*	100	24.5
5	Laragh	*B. pubescens*	20	12.5
6	Laragh	*B. pubescens*	18	11.0
7	Avondale	*B. pendula*	25	19.0
8	Clonsast	*B. pubescens*	15	11.5
9	Clonsast	*B. pubescens*	15	10.5
10	Clonsast	*B. pubescens*	15	9.0
11	Derryvilla	*B. pendula*	15	9.0
12	Portarlington	*B. pendula*	20	15.0
13	Portarlington	*B. pubescens*	18	12.0
14	Portarlington	*B. pendula*	20+	-
15	De Vesey	*B. pubescens*	13	6.0
16	Collin's Bog	*B. pendula*	30	18.0
17	Collin's Bog	*B. pendula*	20	15.0
18	Colt	*B. pubescens*	18	12.0
19	Jamestown	*B. pubescens*	30-40	15.0
20	Athboy	*B. pubescens*	30+	16.0
21	Delvin	*B. pubescens*	13-15	10.0
22	Dromahair	*B. pubescens*	15-18	12.0
23	Drumseanbo	*B. pubescens*	18-20	11.0
24	Derrycarne	*B. pubescens*	15	12.0
25	Roosky	*B. pubescens*	25	17.5
26	Ballydowling	*B. pendula*	45	19.0
27	Shelton	*B. pendula*	50	24.5
28	Tinahealy	*B. pubescens*	25	15.5
29	Humewood	*B. pubescens*	18	11.5
30	Humewood	*B. pubescens*		11.5
31	Avoca	*B. pubescens*	30	15.5
32	Humewood	*B. pubescens*	20	11.0
33	Humewood	*B. pubescens*	20	10.0
34	Bowes Grove	*B. pubescens*	25	17.3
35	Bowes Grove	*B. pubescens*	25	16.2
36	Trooperstown	*B. pubescens*	25	23.0
37	Glanmore	*B. pubescens*	18	18.0
38	Grantstown	*B. pubescens*	35-40	17.5
39	Moyaliff	*B. pubescens*	30	17.0
40	Portnard	*B. pubescens*	20	14.5
41	Shanacashel	*B. pubescens*	15	7.7
42shan	Shanacashel	*B. pubescens*	15	8.0
42	Woodbrook	*B. pubescens*	55	21.0
43	Woodbrook	*B. pendula*	22	17.0
44	Thomastown	*B. pubescens*	40-50	21.5

APPENDIX 3

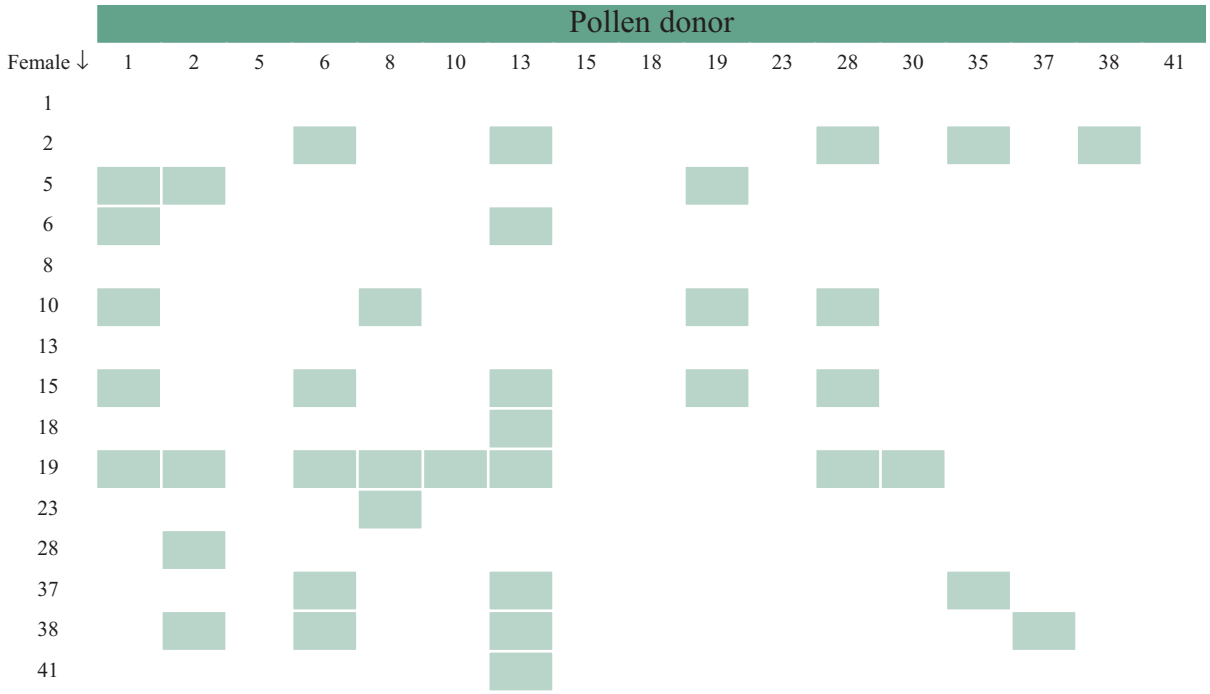
PRODUCTION OF HALF AND FULL-SIBLING PROGENY FOR FIELD TESTING

Seed was produced from controlled crosses between grafted individuals of superior phenotype. Incomplete and disconnected diallele crosses were made. There were insufficient numbers of flowers available at that time to carry out full diallele crosses.

Table 19 lists crosses carried out and included in progeny trials. A total of 37 full-sib seedlots are included in the trials. Further crosses were carried out successfully but did not yield sufficient seed for trial. All of these crosses are *B. pubescens*. Trees are coded 1-50. Birch is monoecious thereby allowing any individual to be used as the female or as the pollen donor.

- *B. pendula* crosses were produced in 2000 and sown in spring 2001 but will not be ready for planting until spring 2002.
- Polymix crosses were carried out for both *B. pendula* and *B. pubescens* and preliminary paternity testing in a 4th year project indicates that pollen donors can be determined (O'Riordan 2001).

Table 19: Controlled pollinations carried out between superior *B. pubescens* phenotypes and included in field trials (denoted by shaded areas).



APPENDIX 4

ESTABLISHMENT OF NINE HECTARES OF PROVENANCE/PROGENY TRIALS

Three 3 hectare sites were planted in spring 2001 with a mixture of provenances/progeny and a small number of clones.

Site	Castletown	Ballyredmond	Boora
Site type	Basic mineral soil	Acidic mineral soil	Cutover industrial peat
Site owner	Farmer	Farmer	Bord na Mona
County	Tipperary	Carlow	Offaly
Size	3 ha	3 ha	2.8 ha
Previous use	Arable crop	Cattle grazing	Rough grazing
Altitude	30 m	130 m	65 m
Aspect	SW	NE	-
Exposure	Moderately exposed	Moderately sheltered	Exposed
Drainage	Moderately well to well drained	Well drained	Poorly drained
Soil association	30 - Grey brown podzolic	12 – Brown earth	44 – cutover peat
Soil description	Patrickswell soil series	Borris series	30-120 cm peat over silty clay loam drift
Parent material	Limestone till with some sandstone and shale	Granite drift	
Mean soil pH - horizon a (n=4)	6.83 ± 0.30	5.94 ± 0.23	7.1-5.0*
Mean soil pH - horizon b (n=4)	7.21 ± 0.49	5.94 ± 0.39	7.2-4.8*
Mean soil pH - horizon c (n=4)	7.57 ± 0.30	5.98 ± 0.21	7.4-4.9
Site preparation	None	Ripped	Ameliorated
Planting method	Machine planted into plough line	Hand planted	Hand planted

● pH of Boora bog given as range as the pH values varied depending upon depth of peat and amount of basic drift ameliorated into soil at sampling point.

Field Trial Experimental Design

● The trials are laid out as single tree plots within randomized, incomplete blocks (Fu *et al*. 1998 and 1999). This design was devised by the authors in conjunction with Prof. Gene Namkoong and Dr Sally Aitken of the University of British Columbia.

● All trees are individually coded to allow families to be observed within provenances. This is to allow for the fact that many provenances are represented by a limited number of families and will allow more rigorous analysis.

● Each provenance is represented on each site by approximately 120 trees. As each provenance is represented by a different number of families (1-9), the number of individuals from a family varies. Table 20 gives approximate numbers of trees per site. These numbers will be confirmed after the sites have been mapped. Exact numbers are unknown because losses from damage during planting are unknown and not all trees supplied to sites were planted due to the final area being planted being less than 3 hectares, e.g. open spaces left for access paths and headlands.

Table 20: The number of *B. pendula* and *B. pubescens* families planted per site (figures are approximate and will be confirmed after sites have been mapped).

Provenance	No. *B. pendula* families	No. of individuals planted/family/site	No. *B. pubescens* families	No. of individuals planted/family/site
Ballydermot	3	40	1	120
Bowes Grove	-	0	5	24
Butlersbridge	-	0	3	40
Clandeboye	-	0	1	120
Collin's Bog	2	60	2	60
Colt	3	40	-	0
Crannadillon	-	0	4	30
Geashill	2	60	2	60
Glanmore	-	0	4	30
Devil's Glen	1	20	-	0
Grantstown	2	60	2	60
Hopkinsrea	1	120	4	30
Humewood	-	0	6	20
Kerry	1	120	4	30
Kilcock	1	120	3	40
Kilcooleyabbey	1	120	2	60
Laragh	-	0	6	20
Lickeen	-	0	2	60
Mountainstown	-	0	4	30
Moyaliff	1	120	3	40
Moyola	-	0	4	30
Mullach	-	0	3	40
Omagh	1	120	6	20
Omeath	1	120	5	24
Park_Hotel	1	20	-	0
Phoenix Pk.	4	30	-	0
Portarlington	1	120	9	13
Shane_Bog	1	120	1	120
Sherwood	-	0	4	30
Tinahealy	-	0	5	24
Trooperstown	-	0	4	30
Scotland 1-7	?	120	0	-

- An additional 37 families from controlled crosses (Appendix 3) were included in the trials with an average of 105 full-sibs per family per site.
- A number of trees have been included in lines for demonstration purposes. These trees will not be included in the overall statistical analysis of the trials. Ten families are each represented by five individuals of similar planting height.
- A double guard row of birch (Kilcooleyabbey provenance) surrounds each site to reduce the edge-effect.
- The two species were not planted intimately but as two adjacent areas on the site. Table 6 highlights the scarcity of *B. pendula.* The *B. pendula* trials are a series of progeny trials rather than provenance trials because the distribution of this species is generally limited to infrequently occurring individuals.

APPENDIX 5

COMPOSITION OF CULTURE MEDIA USED IN THE MICROPROPAGATION OF *BETULA* (MG/L)

Component	C1005	QRC	M3	BET1	GERM1	GERM2	GERMR1
KNO_3	-	-	-	1900	1000	1000	1000
$Ca(NO_3)_2.4H_2O$	556	-	556	-	250	250	250
$(NH_4)_2SO_4$	-	-	-	-	200	200	200
KCl	-	-	-	-	75	75	75
$MgSO_4.7H_2O$	370	370	370	370	125	125	125
KH_2PO_4	170	-	170	170	135	135	135
Sequestrene 330 Fe	40	40	40	40	40	40	40
H_3BO_3	6.2	6.2	6.2	6.2	0.75	0.75	0.75
$MnSO_4.4H_2O$	22.3	22.3	22.3	22.3	0.112	0.112	0.112
$ZnSO_4.7H_2O$	8.6	8.6	8.6	8.6	1.5	1.5	1.5
KI	-	-	-	0.83	0.125	0.125	0.125
$Na_2MoO_4.2H_2O$	0.25	0.25	0.25	0.25	0.125	0.125	0.125
$CuSO_4.5H_2O$	0.25	0.25	0.25	0.025	0.0125	0.0125	0.0125
$CoCl_2.6H_2O$	-	-	-	0.025	0.0125	0.0125	0.0125
myo-inositol	-	50	-	100	45	45	45
thiamine-HCl	-	0.25	-	0.5	0.85	0.85	0.85
nicotinic acid	-	-	-	0.5	0.3	0.3	0.3
pyridoxine-HCl	-	-	-	0.5	0.6	0.6	0.6
pantothenoate	-	-	-	-	0.25	0.25	0.25
d-biotin	-	-	-	-	0.0625	0.0625	0.0625
folic acid	-	-	-	-	0.55	0.55	0.55
l-arginine	-	-	-	-	100	100	100
PVP	-	-	-	-	100	100	100
$(NH_4)NO_3$	400	400	400	1600	-	-	-
$Ca(NO_3)_2.4H_2O$	556	556	556	-	-	-	-
K_2SO_4	990	990	990	-	-	-	-
$CaCl_2.2H_2O$	96	96	96	440	-	-	-
$(NH_4)_2HPO_4$	-	53	-	-	-	-	-
$NH_4H_2PO_4$	-	573	-	-	-	-	-
Activated charcoal	-	3000	-	-	-	-	-
Sucrose	-	20000	30000	30000	30000	30000	30000
Glucose	20000	-	-	-	-	-	-
BAP	0.2	-	0.2	-	-	-	-
KIN	-	-	-	-	0.1	0.025	-
ZEA	-	-	-	-	1.0	0.25	-
IBA	-	-	-	-	-	-	0.1
NAA	0.001	-	-	-	-	-	-
Agar	7500	7500	7500	7500	7500	7500	7500

pH = 6.4 pre-autoclave

There are currently 25 birch clones being micropropagated at UCD.

- Bet4: Initiated from a 101 year old *B. pendula*.
- 1328 and 1523: Initiated from individuals from controlled pollinations.
- Ct1 A-L: A series of half-sib (*B. pubescens*) clones from open pollination in wild.
- Bt1 A-L: A series of half-sib clones (*B. pendula*) from open pollination in wild.